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THE JOURNAL OF POMOLOGY AND HORTICULTURAL SCIENCE is the official organ of the Horticultural and Agricultural Research Station, Long Ashton, Bristol, and the Horticultural Research Station, East Malling, Kent.

The Publication Committee are pleased to consider papers from other sources. Intending contributors should study the Notice on page 3 of this cover.

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EDITORIAL

"When an investigator has completed his work his results possess little value to anyone but himself unless they can receive adequate publication and become known not merely to people engaged in the same sort of work but also to a wider public who are in a position to make use of it."

This was the opening sentence of the Foreword by Sir Daniel Hall to Volume III of this Journal when it became the official organ for publication of the Long Ashton and East Malling Horticultural Research Stations.

No better words could be found to describe the purpose and aim of our Journal to-day, but the rapid expansion of our list of contributors and the ever-widening circle of our subscribers have suggested that we could now with advantage invite Associate Editors overseas to help us in our work.

During recent years, thirty or more papers have appeared under the names of overseas contributors. Sometimes these papers have reported the results of investigations carried out in this country, but an increasing number have dealt with the fundamental problems underlying various aspects of Horticultural Science which have been the subjects of research in countries overseas, and which are of interest to all horticultural investigators whatever their own special lines of work may happen to be.

Hitherto, in order to keep up to date, workers in the science of horticulture have had to scan very carefully the contents of a very large number of scattered publications, and it is thought that their burden in this respect could be lightened by taking more active steps to attract to the pages of the Journal of Pomology a somewhat larger proportion of papers of wide general interest.

The Journal has now a well established circulation amongst all the important University and Horticultural Institutions in some thirty-eight different countries, and it is thought that subscribers would benefit if the Journal could come to be regarded as one of the chief scientific organs for the communication of the results of scientific research of horticultural significance. Should that come about, overseas workers would have a common medium for the publication of their results, having a much wider circulation than is possible for Institutional Bulletins or other similar publications of limited distribution. The Journal would then be able to include articles of even more varied interest than it has hitherto contained. It is not intended, however, to convert it into anything in the nature of an abstracting medium, for such work is already being adequately performed by other organizations. On the contrary, it is considered essential to maintain the Journal as a medium through which horticultural workers can present their findings as fully as is consistent with reasonable limits of space to their contemporaries ; for, it must be remembered that the Pomological and Horticultural Sciences have become recognized as such only in comparatively recent times. The publication of essential data and special methods in some detail is everywhere recognized as helping at this stage to build up a commonly accepted technique of investigation from which deductions can be regarded with a full measure of confidence.

The Publication Committee, then, has agreed with us that the time was ripe to enlist overseas collaboration to facilitate the collection and preliminary editing of contributions from countries outside of the British Isles. The appointment of Associate Editors, who would invite and recommend suitable contributions, who would save time by reading them and suggesting editorial adjustments before final submission, and who would see that the necessary length, summary, requisition form for reprints, etc., were all according to regulation before dispatch, was therefore discussed with the Councils or Departments of Scientific and Industrial Research in several of the most interested Dominions. Following their recommendations, we have already been so fortunate as to be able to add to the list of our Associate Editors the names of:—

Mr. M. B. Davis, B.S.A., M.Sc., Central Experimental Farm, Ottawa, Canada.

Dr. C. Barnard, Division of Plant Industry, Council for Scientific and Industrial Research, Canberra City, F.C.T., Australia.

Mr. L. W. Tiller, B.Sc., Department of Scientific and Industrial Research, Wellington, C.1, New Zealand.

Professor E. E. Cheesman, M.Sc., A.R.C.S., Imperial College of Tropical Agriculture, Trinidad.

Intending contributors from these countries are therefore now asked to submit their papers in the first instance to the Associate Editor in their respective countries.

It is also requested that all those contributing papers dealing with investigations on tropical plants in the Crown Colonies will, in the first instance, submit their communications to Professor Cheesman.

Naturally the Publication Committee on its part will give very serious consideration to the recommendations of its overseas Associate Editors and hope thus to avoid difficulty and delay.

It is intended, as opportunity offers, to invite representatives in South Africa, India and elsewhere to act in a similar capacity.

We feel sure that our contributors will extend to these gentleman as cordial a welcome as does our Publication Committee, and that our readers, like ourselves, will be glad to have their attention drawn to important contributions from overseas which might otherwise have become interred in some Departmental Bulletin, difficult of general access.

Finally, we are glad to inform readers and contributors of our good fortune in having secured the help of Dr. Pethybridge since his retirement from his post at the Plant Pathological Laboratory, Harpenden, in the general editorial work.

B. T. P. Barker.
R. G. Hatton.

A FIELD EXPERIMENT ON THE MANURING OF RASPBERRIES

By T. WALLACE
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The experiment reported in this paper was carried out on the same plots as those utilized for an experiment on gooseberry manuring which was described some ten years ago in this Journal (1). The gooseberry experiment was in progress over the period 1921 to 1932, and after fruiting in the latter year, the bushes were removed in July. During the rest of that summer and autumn the land was thoroughly cleaned and prepared for planting the raspberries in October of the same year.

Subsequent to 1926, the gooseberries were used for chemical investigations (2), and for further observations on the effects of the manurial treatments on growth and fruiting characters and on the incidence of diseases, mainly Botrytis and American Gooseberry Mildew. The ravages of Botrytis in these later years precluded the obtaining of further reliable quantitative records relative to the effects of the manurial treatments on growth and cropping, but qualitative observations were continued, and these showed that no notable changes occurred subsequent to 1926. The experiment remained to the end a most striking demonstration of potash deficiency on the "no manure" and "potash omitted" plots, but characteristic effects due to nitrogen or to phosphorus deficiency were never in evidence.

The present paper reports the results which have been obtained with raspberries over the period from planting in October 1932 to the autumn of 1937.

As with gooseberries, the most important point that has emerged in the raspberry experiment is that potash deficiency is the chief problem on the plots, although nitrogen deficiency also has been in evidence with the raspberries. Phosphorus omission did not produce significant effects in either experiment.

EXPERIMENTAL.

Site and Soil.

These were described in detail in the previous paper (1), where mechanical and chemical analyses for surface soil and subsoil on the east and west blocks of the area were given.

It is thus unnecessary to do more than repeat here that the soil varies over the plots in the general direction north-west to south-east, becoming

lighter in texture towards the latter point. The 1921 soil data showed that the supply of "available" potash was low and "available" phosphate, also, only moderate to poor. The soil at that time was slightly acid although it had just recently been limed. Although not actually determined, nitrogen supplies were probably fairly good, since the land had been broken from old pasture only in 1917.

It was also obvious in very wet periods that certain parts of the area tended to lie wet, and originally this was particularly so in the east section. Prior to the raspberry planting, further attention was given to the drainage of the plots, and this work effected considerable improvement over the wettest parts of the area.

Conditions on this site are, on the whole, fairly suitable for growing raspberries, although damage from wetness is liable to occur in periods of excessive rainfall. Such damage was observed over the plots in 1937, following the previous exceptionally wet summer and winter.

Plot Lay-out and Material.

The total area of the plots is slightly under 1 acre, and it is divided into sixteen strips running north and south, each strip, which comprises a manurial plot, being about 1/18 acre.

As the experimental material, a single row of canes, variety Lloyd George, was planted down the centre of each strip, and lines of the variety Duke of Cornwall were planted as buffer rows along the margins of the strips parallel to the experimental rows. In the autumn of 1935, the variety Duke of Cornwall was removed and Preussen was planted in its place.

The experimental canes were planted approximately 18 in. apart in the rows, giving 80 canes per row, and the distance between an experimental row and a buffer row was at the outset 9 ft. This wide distance between the rows was adopted to prevent suckers from one row running into those adjoining it.

The material used was taken from the Research Station stock beds and was free from rogues and from Mosaic symptoms at the time of planting. Planting was carried out between October 20th and November 6th, 1932, unfortunately during a period of wet weather. The canes after planting were not cut down until the following spring.

Manurial Treatments.

The manurial treatments given to the gooseberry plots were continued on the raspberries so that they have been continuous over the history of the plots. They comprised comparisons of farmyard manure with complete "organics" and "artificials", and included omissions from the complete manure of nitrogen, phosphate and potash respectively, as well as "no manure" treatment.

There were eight different treatments and each was in duplicate but, unfortunately, for reasons given in the account of the gooseberry experiment, the treatments were not randomized and the data cannot be subjected to a complete statistical analysis.

The manures were applied in broadcast fashion in early March each year, the farmyard manure not being specially turned in. Other details of the treatments are given in Table I.

TABLE I.

Manurial Treatments.

Plot Nos.	Manurial Treatments.	
1, 9	No manure.	
2, 10	Farmyard manure, 10 tons.	
3, 11	Complete "organic" manure—	Dried Blood, Steamed Bone Flour, Sulphate of Potash.
4, 12	Complete "inorganic" manure—	Nitrate of Soda, Superphosphate, Sulphate of Potash.
5, 13	Complete mixed "organic" and "inorganic" manure	Ingredients as in 3 and 4.
6, 14	As 5 and 13, without nitrogen.	
7, 15	As 5 and 13, without phosphate.	
8, 16	As 5 and 13, without potash.	

In all treated plots, except those with farmyard manure, nitrogen was at the rate of 50 lb. N per acre, phosphate at 120 lb. total phosphate (approximately, 60 lb. P_2O_5) per acre and potash at 100 lb. K_2O per acre.

MANAGEMENT.

Apart from the unusually wide distances between the rows, the plants have been grown under ordinary commercial methods of management, tractor, horse and hand labour having been utilized. Routine spraying has been carried out against the raspberry beetle.

WEATHER CONDITIONS.

The weather conditions during the experiment have been somewhat unusual at times, abnormally wet and drought periods occurring which greatly affected the growth of the plants at certain stages.

Thus, the winter of 1932-33, immediately following planting, was very wet and mild, and the newly planted canes suffered from soil wetness. This was followed by a summer drought in 1933, which added to the difficulty of establishing the young plants successfully, and extensive replacements were necessary at the end of that season.

Drought conditions again prevailed during the summer of 1934, and they produced marked effects on the canes during picking time and restricted the crop. The following winter was again abnormally wet and mild, and this was followed by a phenomenal May frost in 1935 which destroyed the entire crop. In addition, the summer of that year was notable throughout the country for drought conditions which were severe at Long Ashton until August 22nd. From that date excessively wet conditions prevailed throughout the winter, and continued with only short breaks over the summer of 1936, when conditions were extremely bad during picking time.

After a dry autumn in 1936, another very wet winter occurred and, as a result of this following on the wet summer, much killing of canes was observed in the spring of 1937 over the whole area, irrespective of the manurial treatments. Perhaps the plots to suffer most at this time were Nos. 14 and 15.

RESULTS AND DISCUSSION.

1. General Growth Characters.

Very detailed observations were made each season on the growth characters exhibited by the plants, careful notes being taken relative to the time of coming into leaf, foliage characters, heights of canes, mortality of canes, incidence of Mosaic and defoliation phenomena.

The main general features relating to growth which require mention are the poor growth made in 1933, the first season after planting, due to the previous wet winter and to the summer drought of 1933, and the restricted growth in patches and the killing of canes throughout the plots which occurred as the result of wet winters, especially in 1937. In addition, the loss of crop from frost in 1935 led to subsequent vigorous cane growth which necessitated special thinning of the young canes in that season.

Apart from these points, growth throughout the plots, excepting those under potash deficiency and to some extent those under nitrogen deficiency, was good, the heights averaging about 2 ft. 6 in. to 3 ft. and the numbers of canes tending to be rather large, forming wide rows and necessitating some thinning out.

The numbers of replacements necessary at the end of 1933 are shown in Table II.

Table II.

Cane Replacements, October 3rd, 1933.

	BLOCK A.								BLOCK B.							
Plot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Nos. of new canes planted	30	25	16	18	20	19	7	20	43	25	10	15	11	8	14	24

The amounts of growth on the west and east sections of the area (Blocks A and B respectively) have generally appeared similar, though in B, on the lighter soil, the late autumn tints have sometimes appeared to be more intense, reflecting differences in soil conditions.

The only factor to produce marked growth effects has been the omission of potash, the poorer growth on the "omit potash" and "no manure" plots having been obvious throughout the experiment. Of the four plots receiving these treatments, Nos. 8 and 9 have been much behind Nos. 1 and 16 and have also shown much more evidence of potash deficiency in the form of leaf scorch.

Apart from these two treatments, the only other one to show effects on growth has been nitrogen omission on Plots 6 and 14, where growth has been noted as slightly restricted and where low-nitrogen tints have been in evidence since August 1936.

The order of vigour assigned to the plots from visual observations on August 4th, 1937, was as follows:

Order of Vigour (High to Low).

Block A. 3, 5, 4, 2, 7, 6, 1, 8.
Block B. 13, 12, 11, 10, 15, 14, 16, 9.

Apart from growth, the only other notable feature has been the development of deficiency symptoms in the foliage. Potash deficiency symptoms have been present on Plots 1, 8, 9 and 16 from the first season, generally becoming noticeable in June each year. The symptoms were quite typical, beginning as a slight purpling, followed by brown tinting of the leaf margins, which eventually dried out, producing marginal scorch, and extending later towards the midribs between the veins.

Nitrogen deficiency symptoms were first definitely established in August 1936, the leaves being then of a distinctly paler green colour than those on the other plots and tending to show yellow and red tints towards defoliation time. The condition, however, has not been very marked up to the present.

As will be seen from the quantitative data, the canes on the "omit phosphate" plots have continued to make strong growth, and deficiency symptoms have not yet appeared.

2. MOSAIC.

A few plants showing Mosaic symptoms were observed in 1934 and they were immediately removed. Further cases developed in 1935, but no action was taken until the following season when all suspected plants were removed during September. As the removal of these canes caused considerable gaps in the rows of certain plots (see Table III), it was necessary to adjust the quantitative data for canes and cropping subsequent to that date.

TABLE III.

Lengths of Gaps after Removal of Mosaic affected Canes.

	BLOCK A.								BLOCK B.							
Plot No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Lengths of gaps (feet)	20	8	7	6	0	0	0	15	4	21	15	0	6	40	5	28

The data do not indicate any clear relationship between manurial treatments and Mosaic, for the duplicates show wide variations.

3. PRUNING DATA.

Data are available for the weights of old canes removed subsequent to fruiting time for the three seasons, 1935, 1936 and 1937. In 1935, the canes did not actually bear a crop owing to the May frost, and in that year the canes which should have fruited were removed in June. Thinning of the new growths was carried out on three occasions prior to the 1936 crop in order to encourage growth and to obtain proper spacing of the canes which were crowded in the rows.

The data for the old canes for the seasons 1935-37, together with those for the thinned new growths in 1935, are given in Table IV. The main points which emerge are as follows:

The total prunings for the two Blocks A and B are very similar, being within 1 per cent. of each other. The responses in the two blocks from the different treatments, as measured by the results for the respective " no manure " plots, appear larger in Block B, due to the better growth of the " no manure " plot in Block A, where potash deficiency is less acute than on the remainder of the area. This same fact accounts for the superiority of Plot 1 over Plot 8.

As regards the effects of the treatments, the most striking point is the position of the " no manure " and " omit potash " plots in both series, these being clearly segregated from the remainder. This result shows that potash deficiency is the chief factor in limiting cane growth on the plots.

The position of nitrogen deficiency as a limiting factor is not clearly indicated in the total yields of prunings, Plot 14 occupying third place in Series B ; but if the values for 1937 are examined it is seen that in both blocks the " omit nitrogen " plots, 6 and 14, occupy positions immediately above the four plots not receiving potash. It is thus clear that nitrogen omission in the latest stage of the trial is limiting cane growth.

Phosphorus omission on Plots 7 and 15 is associated with high yields of canes and has not so far proved detrimental.

The highest yields in both blocks are on the " complete mixed organic and inorganic " plots, and the results from farmyard manure appear similar to those from the complete fertilizer mixtures.

TABLE IV.

Pruning Data. Showing Weights of Canes Removed—Kilos.

Block	Plot No.	Manurial Treatment.	Old Canes removed June 1935.*	New Growths removed in Thinning and Tipping. June 1935.	Sept. 1935.	Aug. 1936.	Fruited Canes removed Aug. 1936.	Fruited Canes removed Aug. 1937. (Adjusted for Mosaic removals in Table III.)	Totals.	As % of unmanured.	Order: Highest to Lowest.
Block A.	1	No manure	13·60	10·80	2·12	3·05	8·75	16·96	55·28	100	7
	2	Farmyard manure	17·75	18·40	1·53	5·20	10·25	25·09	78·22	142	2
	3	Complete organic	11·00	20·35	2·00	2·60	10·95	28·91	75·81	138	3
	4	Complete inorganic	14·10	14·60	1·70	3·95	8·10	28·00	70·45	127	5
	5	Complete mixed organic and inorganic	16·00	19·85	1·40	5·30	10·60	30·45	83·55	153	1
	6	Nitrogen omitted	9·30	14·60	1·50	3·10	7·30	19·65‡	55·47	100	6
	7	Phosphate omitted	18·00	13·15	2·00	2·95	11·20	28·50	75·80	138	3
	8	Potash omitted	7·75	9·35	1·65	2·30	6·70	15·93	43·68	80	8
			107·50	121·10	13·90	28·45	73·85	193·51	538·26		
Block B.	9	No manure	7·15	13·35	1·90	2·20	4·70	10·21	39·51	100	8
	10	Farmyard manure	13·00†	15·90	1·50	3·40	8·70	27·95	70·45	175	5
	11	Complete organic	12·05	12·95	1·85	2·80	9·20	24·47	63·32	158	6
	12	Complete inorganic	14·65	15·30	1·70	3·10	10·75	28·35	73·85	185	3
	13	Complete mixed organic and inorganic	25·40	16·60	2·60	4·00	13·20	33·13	94·93	238	1
	14	Nitrogen omitted	22·10	14·60	1·95	2·35	11·75	21·09	73·84	185	3
	15	Phosphate omitted	19·40	16·75	2·35	3·35	12·70	26·06	80·61	203	2
	16	Potash omitted	10·35	8·20	2·00	1·95	6·90	16·58	45·98	115	7
			124·10	113·65	15·85	23·15	77·90	187·84	542·49		

* These did not fruit owing to frost of May 17th.

† Calculated from number of canes.

‡ This weight on low side owing to " burning " of canes during spraying.

TABLE V.

Cropping Data—Kilos.

Block	Plot No.	Manurial Treatment.	1934. 2.7.34 to 20.7.34.	1936. 7.7.36 to 27.7.36.	1937. 28.6.37 to 23.7.37. (Adjusted for Mosaic removals in Table III.)	Totals for three Seasons	As % of unmanured.	Order: Highest to Lowest.
Block A.	1	No manure	7·72	36·65	35·32	79·69	100	7
	2	Farmyard manure	7·00	44·25	55·82	107·07	134	3
	3	Complete organic	6·10	40·05	55·09	101·24	126	5
	4	Complete inorganic	8·08	42·05	54·48	104·61	131	4
	5	Complete mixed organic and inorganic	7·60	46·85	55·70	110·15	138	2
	6	Nitrogen omitted	7·18	39·40	50·89*	97·47	121	6
	7	Phosphate omitted	9·95	46·10	56·10	112·15	140	1
	8	Potash omitted	5·70	39·10	30·70	75·50	95	8
		Total for Block A	..	..	..	787·88		
Block B.	9	No manure	2·58	26·80	21·22	50·60	100	8
	10	Farmyard manure	6·88	39·40	56·58	102·86	220	1
	11	Complete organic	6·86	41·45	42·01	90·32	176	6
	12	Complete inorganic	7·28	49·90	50·05	107·23	210	3
	13	Complete mixed organic and inorganic	7·03	54·35	48·61	109·99	216	2
	14	Nitrogen omitted	8·60	47·25	43·10	98·95	194	4
	15	Phosphate omitted	7·40	47·40	46·34	96·14	188	5
	16	Potash omitted	2·80	24·20	25·48	52·48	102	7
		Total for Block B	..	..	..	708·57		

* This weight also adjusted for spray injury.

4. CROPPING DATA.

The cropping data for the period 1934-37, omitting 1935 when there was no crop, are presented in Table V. The data refer only to summer crops, but it should be added that autumn fruiting occurred on the tips of the young canes in 1934, 1936 and 1937. These berries were not harvested. Autumn fruiting was prevented in 1935 by tipping the new growths in September.

Here, again, there is only an 11 per cent. difference between the total crops for the two blocks, the difference being mainly due to the higher yields on Plots 1 and 8 as compared with those on Plots 9 and 16.

The increases in the crops of fruit in the two blocks due to the manures are, on the whole, similar to those for cane growth, the apparently greater responses again being in evidence in Block B. The "no manure" and "omit potash" plots again form a group, with yields much below those of the other treatments, and potash is shown to be equally essential for fruiting as for cane growth.

Nitrogen deficiency has not reduced fruiting to the same extent as it has cane growth and, even in 1937 in Block B, the "omit nitrogen" plot, No. 14, yielded more heavily than one of the complete fertilizer plots, No. 11.

"Omit phosphate" plots are again grouped with the complete manure treatments and on Plot 7 this treatment has produced the highest total yield of all the plots.

There is no outstanding point regarding the yields for farmyard manure and the various complete fertilizers, and it should be noted that no bad effects have resulted from the use of a purely inorganic fertilizer on Plots 4 and 12, annual dressings of this having been applied since 1921.

COMPARISON OF RASPBERRY AND GOOSEBERRY RESULTS.

It is not possible to make a detailed comparison between the behaviour of the raspberries and the gooseberries in the two experiments owing to the improvements effected in the drainage of the plots, especially in Block B, prior to the planting of the raspberries. The improved drainage is probably largely the cause of the better performance of the raspberries in Block B in comparison with Block A than with the gooseberries, comparative figures for the two experiments being as follows:

	Raspberries.		Gooseberries.	
	Prunings.	Crops.	Prunings.	Crops.
Block A	100	111	161	116
Block B	101	100	100	100

With both crops, potash deficiency has proved the chief problem on the plots and in both experiments the deficiency effects have been more severe in Block B than in Block A. Drainage, however, has greatly improved growth and yields on Plot 16, where the results for gooseberries were the poorest of all plots. Signs of nitrogen deficiency did not appear during the gooseberry experiment and have been in evidence only during the last two years of the raspberry trial. In view of the cropping history of the area, it is possible that this symptom would occur at the present time with gooseberries.

Neither with gooseberries nor raspberries has phosphorus omission produced significant decreases in growth or cropping, and the raspberries under the improved drainage conditions have given excellent results under this treatment.

ACKNOWLEDGMENTS.

Thanks are due to Messrs. C. A. S. Padfield and R. M. Jarrett, who have been responsible for all technical operations and records in connection with the experiment.

SUMMARY.

1. A manurial experiment with raspberries, variety Lloyd George, was carried out over the period 1932-37, on plots previously used for a similar experiment with gooseberries during 1921-32.

2. The manurial treatments given to the gooseberries were continued for the raspberries so that the plots have been under the same treatments since 1921. The treatments included farmyard manure, complete organic manure, complete inorganic manure and complete mixed organic and inorganic manures, as well as the last-named treatment with omissions of nitrogen, phosphate and potash respectively.

3. The amounts of nitrogen, 50 lb. N, total phosphates, 120 lb. (60 lb. approximately P_2O_5) and potash 100 lb. K_2O, were identical for all plots receiving fertilizers.

4. Potash deficiency proved the chief problem of the area and greatly restricted cane growth and cropping. Nitrogen deficiency symptoms were in evidence during the last two seasons of the experiment and were associated with decreased cane growth and fruit yield, the former being more marked than the latter. The omission of phosphorus did not produce any significant effect.

5. The effects of the farmyard manure and of the complete fertilizers were of a similar order.

6. The results for raspberries were generally similar to those for gooseberries, potash deficiency being the chief problem in both cases. Nitrogen deficiency effects were observed with raspberries but not with gooseberries.

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(2) ———. The Effects of Manurial Treatments on the Chemical Composition of Gooseberry Bushes. *Ibid.*, 1928, **7**, p. 130.

(*Received* 5/12/37.)

THE INCORPORATION OF DIRECT WITH PROTECTIVE INSECTICIDES AND FUNGICIDES

III. FACTORS AFFECTING THE RETENTION AND SPRAY RESIDUE OF EMULSIONS AND COMBINED EMULSION-SUSPENSIONS

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INTRODUCTION.

The main subject of the investigations recorded in this series has been the physico-chemical properties which determine the amount of spray fluid retained by sprayed surfaces and the tenacity of the resultant spray deposit. The first paper (7) was concerned with the laboratory evaluation of water-soluble spray supplements as wetters and spreaders, an important aspect of which was the effect of the supplement on the maximum amount of solution retainable upon the surfaces. In Part II (8) were described the effects of the supplement on the retention and tenacity of deposits remaining after the application of suspensions, i.e. of sprays consisting of a solid and a liquid phase. In the present paper the sprays examined have included emulsions representing two liquid phases and, finally, sprays consisting of finely divided solids suspended in emulsions, i.e. solid / liquid / liquid systems

Emulsions are now widely used as horticultural sprays and the insecticidal and acaricidal efficiency of petroleum oils is well established. The realization that such emulsions, by virtue of the excellent penetrating and spreading properties of the oils, are effective carriers of oil-soluble direct (contact) insecticides is of later date. Thus, the value of Penetrol (10) as a so-called "activator" for nicotine is probably due to the unsulphonated petroleum oil present (14). Austin, Jary and Martin (1) showed that cottonseed oil-Bordeaux, an emulsion containing no water-soluble wetter, is an excellent vehicle for nicotine. More recently de Ong (4) has described the use of pine oil as a penetrant and carrier for oil-soluble copper fungicides, whilst the efficiency of the nicotine sprays devised by Eddy (6) is probably associated with the pine oil present.

It is evident that the performance of oil emulsions both as active insecticides and as penetrants will, apart from the specific properties of the oil present, be determined by the amount of oil deposited upon the sprayed surface. This point was examined in the early studies of de Ong, Knight and Chamberlin (5)

who showed that it explained the inhibiting effect of relatively high concentrations of emulsifier on the scale-killing properties of petroleum oils. They found that, as the amount of emulsifier (calcium caseinate) was reduced, the insecticidal efficiency of the emulsion was increased and the proportion of oil present in the spray draining from the surface decreased. Maximum insecticidal efficiency was obtained when emulsification conditions were such that an oil film developed. Their results were confirmed by Cressman and Dawsey (2), who concluded that the insecticidal efficiency of a particular petroleum oil applied in soap emulsions showed a quantitative relationship to the amount of oil deposit which, in turn, varied directly with the concentration of oil in the emulsions applied and indirectly with the concentration of soap emulsifier in the aqueous phase of the emulsions. The observations of de Ong *et al.* on the importance of the formation of an oil film run parallel to those of Martin and Salmon (16) on the direct fungicidal efficiency of various terpene oils. The latter results indicated that effective fungicidal action was associated with a particular type of wetting which was described as "oily" wetting. It is probable that this mode of wetting was due to the separation of an oil film upon the leaf surface which consequently became less completely wetted by the aqueous phase of the spray.

It appeared therefore that, for the present investigation, it would be advantageous to distinguish two factors accounting for the quantity of oil deposit: firstly, the amount of oil present in the emulsion retained upon the surface, which would contribute to the oil deposit after evaporation of the water phase of the emulsion; secondly, the amount of free oil, formed as an oil film during the application of the emulsion, by the preferential retention of oil upon the surface.

The addition of a solid phase to the emulsion introduces other items requiring examination. Firstly, the interaction of the solid with the emulsifier present may result not only in obvious chemical reactions, but in changes of the physical condition of both emulsion and suspension. Secondly, the solid present may influence both the retention of the emulsion and the ability of the spray to yield an oil film. Thirdly, the effects of the emulsion on both retention and tenacity of the solid require investigation.

The final stage of the work has been the application of the conclusions of the laboratory investigations to field conditions, and an attempt has been made to substantiate the laboratory findings by field trial.

LABORATORY TRIALS.

EXPERIMENTAL METHODS.

(1) *Emulsions used.* For most experiments a highly-refined petroleum oil (Grade G) (15) was used but, in certain trials on tenacity, a cottonseed oil of free fatty acid content below 1 per cent. was substituted. Stock emulsions were

prepared by milling 2 parts by volume of oil with 1 part of the aqueous emulsifier solution in a laboratory emulsifier of the homogenizer type. These emulsions, containing 67 per cent. by volume of oil, were diluted with water to an emulsion of the required oil concentration.

The emulsifiers used included the following materials:

Sulphite lye (13): a soda-base syrup of 60° Tw.

Sodium oleate: prepared by the two-solution method (12), the required amount of oleic acid being added to the oil and the solution then being poured into dilute sodium hydroxide solution of the required concentration.

Lime casein: prepared by the mixing of 4 parts by weight of hydrated lime and 1 part commercial casein.

Agral S.R.: a proprietary emulsifier, described as consisting essentially of peptized glue containing salts of sulphonated aromatic hydrocarbons.

Dextrin: a commercial product.

(2) *Solids used.* For the investigation of solid retention and the effects of solids on oil retention, a commercial red cuprous oxide was used but, in work on the influence of oil emulsions on the tenacity of solids, a cuprous iodide suspension was substituted. Particulars of the cuprous oxide and of the method of preparation of the cuprous iodide were given in Part II (8).

(3) *Surfaces used.* The artificial surfaces employed were glass plates or aluminium sheets coated with either paraffin wax, cellulose nitrate or a thermal-hardening glyptal resin. Particulars of the methods of preparation of these surfaces were given in Parts I and II (7, 8).

(4) *Estimation of Emulsion Retention.* It is known from previous work (7) that the maximum amount of spray which can be retained upon a vertical surface is that which, applied to one held rigidly perpendicular to the axis of the spray cone, is necessary to initiate run-off or drain-off. This quantity was determined by the atomizer and pendulum method previously described (7).

(5) *Estimation of Free Oil Retention.* For the estimation of the relatively small amounts of oil preferentially retained by the surface, a colorimetric method was devised. The petroleum oil was saturated with an oil-soluble red dye, the dyed oil being emulsified in the manner described. Sprays were prepared by dilution of the stock emulsions to 0·7 per cent. oil. As large quantities of spray had, in most cases, to be applied before determinable amounts of oil film were formed, the pendulum between atomizer and surface was removed. The surface, delimited by a glass plate with an aperture of 2 sq. inches, was then drenched with the spray for a known time. This time, from which the volume of spray and of oil applied could be calculated, was varied according to the amount of oil film formation. Oil retained in emulsified form was washed off with water and, after the plates were dry, the deposited

oil was removed with ether ; the latter was allowed to evaporate off and the residual stained oil was dissolved in 4 ml. unstained oil. This solution was transferred to a micro-Nessler tube and its colour matched by adding, to a comparative tube, known volumes of stained oil (1/10th saturated solution) from a micro-burette.

(6) *Determination of the Stability of Emulsions.* The term stability is here used in the special sense of the rate at which the diluted emulsion separates to layers of different oil concentration. Greater account was therefore taken of the rate of creaming than of the occurrence of breaking ; and, as oil of the same density was used throughout, and the aqueous phase was, in all cases, so dilute that differences in density can be neglected, the method gives an indirect measure of the size-distribution of the oil droplets.

A vertical glass tube (81·3 cm. long $\times$ 2·6 cm. diameter) was filled with the diluted stained oil emulsion used for the estimates of free oil retention. At intervals the upper layer of the emulsion was sampled through a side tube, the oil present in the sample was extracted with ether and its volume determined by the colorimetric method described above. A time-accumulation curve was thereby obtained from which was interpolated the time at which half the total oil content of the emulsion had risen in the cream.

(7) *Examination of the Compatibility of Solids with Oil Emulsions.* It was found that the addition of solid particles may affect profoundly the characteristics of the emulsion and that, in this effect, the type of emulsifier present had as important an influence as the nature of the solid. To elucidate the point, different solids were shaken with emulsions compounded with various emulsifiers and the interaction, if any, observed.

(8) *Estimation of Retention of Emulsions and Free Oil in the Presence of Solids.* The sample of cuprous oxide described under (2) above was used throughout these trials and was added in one of two ways. Either the required amount of cuprous oxide was added to the diluted emulsion of 0·7 per cent. oil (Method A) or it was added to the stock emulsion and the mixture diluted to an oil content of 0·7 per cent. (Method B). The retention of the oil emulsion and the extent of oil film formation were determined by the methods described above.

(9) *Determination of Solid Retention.* Observation of the volume of spray required for incipient run-off provides a measure of the maximum retention of solid dispersed in the spray ; but the possibility that, by the continued application of spray after the point of run-off, the residue of solid may be increased by preferential retention requires examination. For this purpose a delimited area of the surface was exposed to the emulsion-cuprous oxide spray, and the volume of spray applied was regulated by the number of swings of the

pendulum, as described in Part II (8). The solid retained by the surface was washed off with warm dilute nitric acid, organic matter was destroyed by evaporation with sulphuric acid and the amount of copper was estimated colorimetrically by the ferrocyanide method.

(10) *Estimation of Tenacity.* Reference has already been made (8) to the difficulty of obtaining an absolute figure for tenacity, independent of the apparatus used. The empirical procedure adopted was shown, however, by field and laboratory trials, to allow spray supplements to be arranged in order of favourable and unfavourable effect upon tenacity. A similar method was therefore employed in the tests to be described.

For the preparation of cuprous iodide spray residues of known copper content, a delimited area of the surface (1 sq. inch) was sprayed with an amount of fluid not exceeding that required to cause run-off. The plates were allowed to dry at room temperature for twenty-four hours. The spray deposit was then drenched with water under standard pressure from the atomizer for one minute. The deposit still remaining was dissolved in warm nitric acid and, after destruction of the organic matter, the copper present was determined by the ferrocyanide method. The amount of copper remaining, expressed as a percentage of the amount initially applied, was termed the tenacity.

It was subsequently found that, owing to the excellent properties as stickers, of some of the emulsions used, a more drastic leaching treatment was necessary. A larger atomizer was therefore used and 200 ml. of water applied in about 40 sec. with greater pressure to the surface. As the cellulose nitrate surfaces were ruptured by this treatment, it was applied only to the glyptal resin surfaces.

EXPERIMENTAL RESULTS AND DISCUSSION.

To simplify tabulation and discussion, the data concerning emulsions without and with added solids have been assembled together. The first point for discussion then becomes the interaction between emulsion and finely divided solid, for this phenomenon was found to be of importance in connection with emulsion and solid retention.

(1) *Compatibility of Emulsions with Solid Particles.* The extreme type of interaction results, on mere agitation with solid particles, in a complete removal of the oil from the emulsion. After standing a few moments, the aqueous phase is devoid of dispersed phase and the solid particles become flocculated to large aggregates which either settle rapidly or rise as a cream. A typical example is illustrated in Fig. 1, Plate I. The two cylinders contain similar dilutions of petroleum oil and cuprous oxide, the only difference being the emulsifier present. In the cylinder on the right, Agral S.R. at 10 per cent.

is used for the emulsification of the oil. The added cuprous oxide has removed the oil entirely from the emulsion, and the large oil-solid aggregates occupy a comparatively large settling volume.* In the cylinder on the left, sulphite lye (20 per cent. syrup) is present as emulsifier, and no removal of oil by the added cuprous oxide is visible. The effect is also shown in Fig. 2, Plate I, showing micro-photographs of the same two mixtures. On the right, a typical oil-solid aggregate of the Agral S.R. mixture is shown, whilst on the left, the solid particles present in the sulphite lye emulsion are independent of the oil globules.

With other solids and emulsifiers the interaction may not proceed so completely and it was possible to differentiate four grades. The results of shaking emulsions of petroleum oil, compounded with different emulsifiers, with various finely divided solids likely to be used as protective spray constituents are assembled in Table I, and the very strong interaction described above is

TABLE I.

Compatibility of Emulsions and Solids.

Solid.	Emulsifier.			
	Agral S.R. 10%†	Sodium oleate 0·7%	Lime casein 10%†	Sulphite lye: 20% syrup.†
Lime	I	I	I	III
Bentonite	I	I	I	IV
Calcium arsenate	I	I	I	IV
Lead arsenate	I-II	II	I-II	IV
Bordeaux mixture ..	I	I-II	I	IV
Cuprous oxide	I	II	II	IV
Cupric oxide	I-II	II	II	IV
Coposil‡	I-II	II	I-II	IV
Barium sulphate	II	II	I	IV

† Concentration of emulsifier in disperse phase of stock emulsion; with sodium oleate, the concentration is that of the disperse phase of the dilute emulsion.

‡ A proprietary fungicide of which the active constituents are copper silicates, yielding 15 per cent. metallic copper and 3 per cent. metallic zinc.

referred to as I. Interaction of Type II results in pronounced flocculation of the solid, and only a small amount of oil is still left in an emulsified condition. Type III indicates that a small amount of oil forms agglomerates with the solid, whilst Type IV indicates no visible interaction.

The emulsion compounded with sulphite lye was the only one of those tested which gave no indication of interaction with the added solids. In cases

* That the oil is apparently no longer emulsified in the cylinder containing Agral S.R. is obviously not to be interpreted as a failure of this product as an emulsifier. In the absence of the solid, excellent emulsions resulted and, as will be discussed later, the ability of the emulsifier to induce oil-flocculation of the solid may be of value in spray practice.

of slight interaction, visible only after an interval of time, it was possible to accelerate the process by vigorous shaking or by heating. When the solids were added to the stock emulsion before dilution, the interaction, if any, was always complete.

These observations suggest that the interaction is explained by a chemical reaction between solid and emulsifier. The formation of the calcium soap when lime, calcium arsenate or Bordeaux mixture is added to the sodium oleate emulsion is an obvious example and, if soluble salts of lead, copper or calcium (metals forming the cations of most of the solids used) are added to the aqueous emulsifier solutions, interaction is evident. As shown in Table II, solutions

TABLE II.

Compatibility of Emulsifier Solutions and Emulsions with various Salt Solutions.

Solution added.	Emulsifier.							
	Agral S.R.		Sodium oleate.		Lime casein.		Sulphite lye.	
	Sol.	Emul.	Sol.	Emul.	Sol.	Emul.	Sol.	Emul.
Copper sulphate ..	Pptd.	I	Pptd.	I	Curds	I	Nil	Curds after 1 minute
Calcium chloride ..	Pptd.	II	Pptd.	Breaks	Pptd.	I-II	Nil	IV
Lead acetate ..	Pptd.	I	Pptd.	I	Pptd.	I	Nil	IV

of these salts produce interaction with the emulsions analogous to that given by the solids. The slighter interaction of copper sulphate with the sulphite lye emulsion is reflected by the observation that, in emulsions of which the sulphite lye concentration of the stock emulsion was reduced to 2 per cent., some agglomerates of oil and cuprous oxide are found when the latter is added. The reaction appears, in this case, to proceed far enough to prevent the formation of a stable interface protecting the oil globules from the added solid.

(2) *Spray Retention.* The average results of the estimate of initial retention of various emulsions with or without added solid are given in Table III. The figures represent the maximum amount of spray in milligrams per square inch which can be applied to the surface without any run-off. The figures for any one emulsifier concentration and surface were obtained under strictly similar conditions but, as each series was obtained on different days, they are not directly comparable. Water alone was included in each to provide a basis for comparison. This figure is given on the left-hand side of each series. The next column contains the results with aqueous solutions of the emulsifiers, at the same concentration as present in the emulsions of which

TABLE III.

Initial Retention (mg./sq. inch) of Sprays.

Emulsifier: concentration in aqueous phase of stock emulsions.		Paraffin wax.					Cellulose nitrate.				
		Water alone.	Emulsifier solution.	Emulsion.	Emulsion plus solid.*		Water alone.	Emulsifier solution.	Emulsion.	Emulsion plus solid.*	
					A.	B.				A.	B.
Lime casein	10%	192	247	220	227	211	202	60	115	119	205
	4%	192	246	209	197	190	202	87	119	190	198
	0·5%	192	195	195	190	192	202	196	205	202	204
Agral S.R.	10%	185	300	195	254	230	200	56	81	83	100
	5%	185	242	193	270	264	200	92	104	106	116
	1%	185	197	183	182	182	200	149	176	192	194
Dextrin	10%	200	182	193	214	209	214	88	182	193	206
	5%	200	200	200	198	199	214	94	196	200	200
	0·5%	202	202	198	198	205	214	141	208	220	220
Sulphite lye	20%	180	174	180	180	180	198	160	171	170	172
	10%	180	177	179	179	179	200	158	168	170	170
	1%	180	182	183	183	181	196	192	191	195	196

* A. Cuprous oxide added to diluted emulsion.

B. Cuprous oxide added to stock emulsion and mixture diluted to 0·7 per cent. oil.

the data are recorded in the neighbouring column. Thus, the figure 195 for Agral S.R. solution upon the paraffin wax surface refers to a solution of 0·033 per cent. Agral S.R. corresponding to the 10 per cent. solution present in the stock emulsion. In the emulsion plus solid column, the results obtained by the two ways adopted of adding the solid, i.e. A to the dilute emulsion, B to the stock emulsion prior to dilution, are quoted.

Upon the more readily water-wetted cellulose nitrate surface the emulsifier solutions show an initial retention lower than that of water, a general property of wetting-agents described in Part I of this series (7). Upon the paraffin surface the emulsifier, at the low concentrations used, may lead to an increased initial retention, a phenomenon which has been observed in previous work (e.g. with saponin, sulphite lye and gelatine). The initial retention of the individual emulsions is intermediate between that of the emulsifier solution and that of water, except in a few cases where the two latter amounts show differences of a minor order, probably within the experimental error. It would appear that adsorption of the emulsifier at the oil/water interface reduces the emulsifier concentration of the bulk of the aqueous phase. If this explanation is correct it follows that the initial retention of the systems examined depends on the properties of the continuous phase.

The influence of the addition of the solid is dependent on the extent of its interaction with the emulsion. In compatible systems, such as sulphite lye-cuprous oxide, no differences in retention of emulsion and emulsion-solid are shown. In incompatible systems the extent of the differences is related to the extent of interaction. Thus, if the solid is added to the stock emulsion (Method B), it has usually a greater effect on retention than if added to the diluted emulsion (Method A), and it has already been noted that the extent of interaction is generally greater in the former method. It is probable that the interaction when solid is added proceeds more or less slowly, a time factor thus appearing. An experimental verification of this hypothesis was obtained with the lime casein emulsion. The retention figure of the 4 per cent. lime casein emulsion upon cellulose nitrate was determined at intervals after the addition of cuprous oxide. Initially the figure was 120 mg. per square inch, but half an hour after mixing it had risen to 190 mg. per square inch, a figure approaching that obtained with water alone. In incompatible systems the effect of the addition of the solid is to bring the retention figure nearer to that of water alone, a second confirmation of the conclusion that the retention figure is determined by the properties of the continuous phase.

(3) *Free Oil Retention*. The retention studies recorded under (2) above were concerned with the initial retention of the spray. The question arises as to the conditions under which a build-up of the amount of the oil component of

the spray can occur, the result of preferential retention of the oil. For this purpose it is evident that amounts of spray in excess of those producing run-off must be applied and, for the purpose in hand, spraying was continued for various times. The amount of free oil residue was determined and the time taken to deposit 0·0035 ml. per square inch interpolated. From this time the total volume of spray applied was calculated and the results, assembled in Table IV, are expressed as the percentage of total oil applied which remains as a residue of free oil.

TABLE IV.

Free Oil Retention as Percentage Total Oil Applied.

Emulsifier: concentration in aqueous phase of stock emulsion.		Paraffin wax.			Cellulose nitrate.		
		Emulsion.	Emulsion and solid.*		Emulsion.	Emulsion and solid.*	
			A.	B.		A.	B.
Lime casein	10%	22	5	2	37	37	8
	4%	15	2–3	2–3	45	23	23
	0·5%	39	15	15	62	62	62
Agral S.R.	10%	1	22	22	9	45	45
	5%	11	22	22	23	45	45
	2%	23	34	34	45	50	50
Dextrin	10%	0	0	0	2–3	2–3	3
	5%	1–2	1–2	2–3	7·5	9	17
	2%	6	6	6	30	30	30
	0·5%	15	15	15	50	54	54
Sulphite lye	20%	0	0	0	0	0	0
	0·5%	1–2	1–2	9	9	20	37

* A. Cuprous oxide added to diluted emulsion.
B. Cuprous oxide added to stock emulsion and mixture diluted to 0·7 per cent. oil.

The results obtained with emulsions alone are in agreement with the earlier observations of de Ong *et al.* (5) and of Cressman and Dawsey (2), viz. that the extent of free oil retention increases inversely as the emulsifier concentration. The relationships between the stability of the emulsions and the extent of free oil retention are illustrated in Fig. 1, in which the percentage oil retained as free oil upon a cellulose nitrate surface is plotted against the time taken for half the oil content of the emulsion to collect in the upper layers. The curves demonstrate that free oil retention is dependent not only on the emulsifier concentration but on the nature of the emulsifier. Moderately stable lime casein emulsions, for example, permit free oil retention, whilst sulphite lye emulsions of the same stability leave no significant free oil deposit.

Upon the paraffin surface a lower degree of free oil retention is shown than upon cellulose nitrate but its extent is likewise dependent on content and

nature of the emulsifier. Further, it would appear that the relative amounts of free oil deposited are not similar, being, for example, 39:62, 23:45, 15:50 and 1-2:9 for the lowest emulsifier concentrations of lime casein, Agral S.R., dextrin and sulphite lye respectively. This observation is in agreement with the conclusions of Dawsey, Cressman and Hiley (3) on the different ratios of the oil deposits upon foliage and paraffin-coated plates when different emulsifiers are used. No critical tests were made to determine the nature of the factors affecting the ratio but, in connection with the hypothesis that the extent of

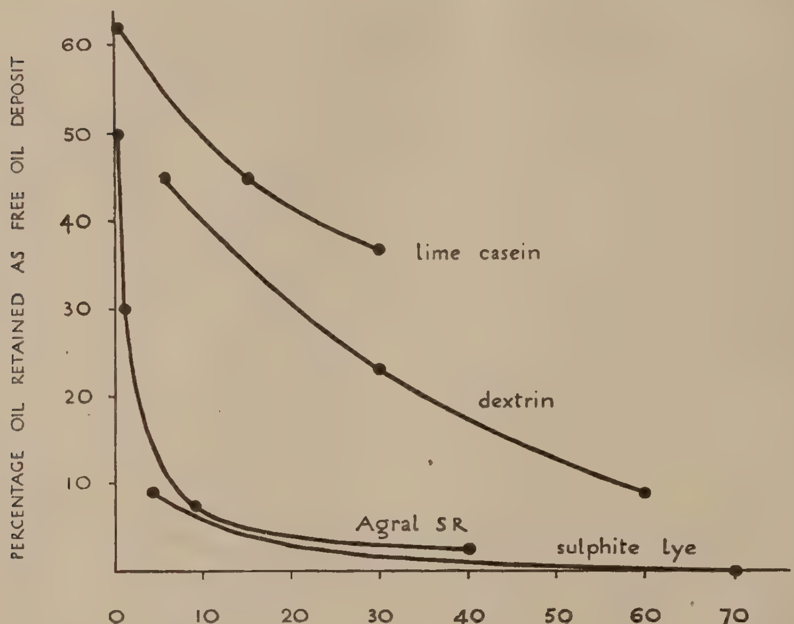

Fig. 1.

The Preferential Oil Retention and Stability of Emulsions.

Free oil retained expressed as percentage of oil applied.

Stability expressed as time (hours) taken for half the oil volume to layer.

free oil retention may be determined by the relative wetting properties of the continuous and disperse phases of the emulsion, the following experiment may be quoted. The addition of a water soluble spreader (Sulphonated Lorol) at 0·05 per cent. to an unstable sulphite lye emulsion, prepared by the dilution to 0·7 per cent. oil of a stock emulsion containing 0·3 per cent. sulphite lye as emulsifier, did not alter the extent of free oil deposition (30 per cent.). As the continuous phase of the emulsion plus spreader wetted the cellulose nitrate surface perfectly, it would not appear that the wetting properties of the emulsion affect free oil retention.

The effect of the addition of solid on free oil retention is erratic but, in most cases, follows the rules indicated above. If an interaction occurs between solid and emulsifier the stability of the emulsion is reduced and oil retention correspondingly increased. By the same rule, as the effects of interaction are more pronounced when the solid is added to the stock emulsion (Method B), the percentage figure for oil retention is higher than in column A ; e.g. the more concentrated dextrin emulsions upon the cellulose nitrate surface or the more dilute sulphite lye emulsion upon both surfaces. When no evidence of interaction is visible, as in the more concentrated sulphite lye emulsions, the addition of the solid has no effect on free oil retention. The important exception to these rules occurs with lime casein, but it will be noted that the free oil retention of lime casein emulsions is relatively high in the absence of a solid phase.

(4) *Retention of the Solid Phase.* The amount of solid retained at run-off may be calculated from the data given in Table III, but it remains to be seen whether, by continued application of the spray after the point of run-off, the amount of the solid deposit can be augmented by preferential retention. Typical results are given in Table V, which concerns the amounts of cuprous oxide residue expressed as mg. Cu per square inch, formed upon a cellulose nitrate surface sprayed with increasing amounts of cuprous oxide-petroleum oil emulsions.

TABLE V.

Retention of Cuprous Oxide-Oil Emulsion on Cellulose Nitrate.

Emulsifier 10% Agral S.R.			20% Sulphite lye.		
No. of exposures.	mg. Cu./sq. in.		No. of exposures.	mg. Cu./sq. in.	
	Applied.	Retained.		Applied.	Retained.
8	0·22	0·22	12	0·32	0·31
13	0·35	0·35	16	0·42	0·41
30	0·81	0·48	40	1·02	0·35
40	1·08	0·69	50	1·31	0·36
50	1·35	0·75	90	2·36	0·28
80	2·16	1·08	100	2·70	0·38
100	2·70	1·28			
	Run-off at 14 exposures.			Run-off at 17 exposures.	

When applied with the sulphite lye emulsions no preferential retention of the cuprous oxide occurs, the maximum deposit coinciding with the point of run-off. When mixed with the Agral S.R. emulsion, the cuprous oxide is precipitated as a solid-oil agglomerate and preferential retention occurs, a cuprous oxide-oil deposit being built up as spraying is continued.

(5) *Influence of the Oil Emulsion upon Tenacity.* The results, each the mean and standard error of six replicated estimations, of the determination of the copper remaining upon plates sprayed with cuprous oxide-oil emulsions after the given leaching treatments, are expressed in Tables VI and VII as

TABLE VI.

Tenacity of Cuprous Iodide-Oil Emulsions on Glyptal Resin.

Emulsifier : concentration in aqueous phase of stock emulsion.	Petroleum oil.				No oil.	Cottonseed oil.		
	2%	1%	0·5%	0·25%	0%	1%	0·5%	0·2%
Sulphite lye (20%)	—	17±1·7	56±2·0	51±1·8	—	55±2·5	75±2·3	87±1·1
(10%)	—	25±2·8	56±3·3	61±3·3	—	97±2·1	97±4·0	88±1·2
(5%)	33±3·3	37±4·9	81±2·6	68±3·2	—	—	—	—
(2%)	51±4·0	77±6·6	83±1·9	87±4·5	—	—	—	—
Without added emulsifier	—	75±2·0	78±3·7	70±3·7	—	—	95±1·7	88±1·7
Without oil or emulsifier	—	—	—	—	52±2·0	—	—	—
Gelatine (0·1%)*	—	96±2·4	88±2·2	—	68±5·0	—	—	—
Agral S.R. (0·05%)*	—	73±5·7	—	—	57±1·0	—	—	—

* Concentration in spray applied.

TABLE VII.

Tenacities of Cuprous Iodide-Oil Emulsions on Cellulose Nitrate.

Sulphite lye : concentration in aqueous phase of stock emulsion.	Petroleum oil.		
	2%	1%	0·5%
20%	21±1·4	27±3·1	38±1·6
10%	23±2·6	53±1·9	90±3·0
5%	41±1·4	64±4·3	92±1·1
2%	100	100	100
Without oil or emulsifier	30±3·6		

percentages of the original spray residue. The main experiments were made upon glyptal resin surfaces and are assembled in Table VI, but a series of confirmatory tests was made upon cellulose nitrate surfaces (Table VII).

It is evident from these results that the influence of the oil emulsion on the resistance to leaching of the cuprous iodide residue upon the glyptal resin

surface is determined by the amount and character of both oil and emulsifier. Sulphite lye, the deleterious effect of which upon tenacity is described in Part II (8), yields emulsions which exert a favourable or unfavourable effect on tenacity according to the oil/emulsifier ratio. As the sulphite lye content of the spray is increased the tenacity figure falls. Gelatine and Agral S.R., which alone exert a favourable effect upon tenacity, each yield emulsions possessing good sticking properties.

The oils in sprays in which the cuprous iodide itself functioned as emulsifier, are shown to promote tenacity, cottonseed oil being superior in this respect to the petroleum oil used. Where, however, sulphite lye is also present the favourable effect of the presence of oil on tenacity is masked by the deleterious effect of the emulsifier. Thus, in each horizontal series of both Tables VI and VII, the tenacity figure decreases as the oil content of the spray is increased, for with oil content the sulphite lye concentration of the spray also increases. A comparison of the tenacities of sprays of the same sulphite lye content may be made by reading pairs of tenacity figures diagonally. Thus, the 1 per cent. dilution of the 20 per cent. sulphite lye stock emulsion yields the same emulsifier concentration as the 2 per cent. dilution of the 10 per cent. sulphite lye stock emulsion, but the oil concentration of the first spray is half that of the second. With petroleum oil emulsions the addition has no marked influence upon tenacity, the majority of the differences being within the experimental error. With the cottonseed oil emulsion, the increased oil content furnishes higher tenacity figures, a confirmation of the conclusion that the effect of cottonseed oil on tenacity is more favourable than that of petroleum oil.

FIELD TRIAL.

In parallel with the laboratory investigations, a trial was arranged to determine the influence of various emulsions on the field performance of a protectant fungicide. Cuprous oxide, from the same bulk of the commercial red product employed in the laboratory trials, was selected as the fungicide, potato as the test plant and the degree of control of potato Blight was used as the criterion of fungicidal efficiency.

Experimental Methods.

(1) *Lay-out of Trial.* A block of King Edward potatoes was subdivided into ten strips of eleven paces' width running across thirty potato rows. Each strip was further divided into fifteen plots, each consisting of two rows, and to each of these plots one of the fifteen spray treatments was applied. The trial thus comprised ten randomized blocks with the further precaution that no similarly treated plot appeared twice along the rows.

(2) *Sprays Used.* The main investigation was of the influence of type of emulsifier and of oil and emulsifier concentration on the retention and tenacity of the cuprous oxide, sulphite lye and Agral S.R., each being used as emulsifier, cottonseed oil (a cheap edible grade) and petroleum oil (Grade G) being used as the oils. Two treatments (H and O) were included but, as these had no direct connection with the problems under discussion, no details need be given. Unsprayed plots, and plots sprayed with ordinary Bordeaux mixture were included for check purposes.

The full list of treatments thus becomes:

Treatment	A.	Bordeaux mixture (8:12:100); 0·2% Cu.
,,	B.	Red cuprous oxide, 0·2% Cu, 0·2% petroleum oil, 0·02% sulphite lye.
,,	C.	,, ,, ,, ,, 0·2% petroleum oil, 0·005% sulphite lye.
,,	D.	,, ,, ,, ,, 1·0% petroleum oil, 0·1% sulphite lye.
,,	E.	,, ,, ,, ,, 1·0% petroleum oil, 0·025% sulphite lye.
,,	F.	,, ,, ,, ,, 0·2% cottonseed oil, 0·02% sulphite lye.
,,	G.	,, ,, ,, ,, 0·2% sulphite lye.
,,	J.	,, ,, ,, ,, 0·1% sulphite lye.
,,	K.	,, ,, ,, ,, 0·2% petroleum oil, 0·01% Agral S.R.
,,	L.	,, ,, ,, ,, 0·2% cottonseed oil, 0·01% Agral S.R.
,,	M.	,, ,, ,, ,, 0·01% Agral S.R.
,,	N.	,, ,, ,, ,, no supplement.
,,	P.	Unsprayed.

(3) *Spray Application.* For the reasons stated in Part II (8) of this series, each plot received 1 gal. of spray. With the rapidly settling suspensions, K, L and N, continuous and vigorous stirring of the contents of the can was necessary throughout the application to ensure an even distribution of the protectant.

The first application was made on July 16th and completed under good weather conditions, which held until the middle of August, and a repeat application of the sprays was made on August 10th, again under excellent conditions. No Blight lesions were seen until September 1st, when they were found in all the unsprayed plots.

(4) *Estimation of Spray Residue.* For the estimation of the amount of copper protectant remaining on the foliage throughout the trial, periodic samples were taken. Twenty-five leaflets were collected at random from each plot and the ten samples per treatment were mixed in the laboratory. From each leaflet a disc of 1·415 cm. diameter was cut with a cork borer, care being taken to avoid the edges and tips of the leaflets. Five samples, each of fifty discs, were thus obtained for each spray treatment. These were ashed separately and

the amount of copper present determined by the colorimetric ferrocyanide method.

(5) *Estimation of Blight Infestation.* The method described in Part II of this series (8) was employed.

EXPERIMENTAL RESULTS.

(1) *Estimation of Spray Residue.* Foliage sampling was made as soon as possible after each spray application and was repeated at approximately ten-day intervals. The full results are summarized in Table VIII in which the mean amount (and standard error) of copper is expressed as mg.Cu $\times 10^{-1}$ per fifty leaf discs of diameter 1·415 cm.

TABLE VIII.

Estimates of Copper Residues.

Spray.	19.6.37.	29.7.37.	9.8.37.	11.8.37.	19.8.37.	1.9.37.	14.9.37.
A	12·8±0·50	5·6±0·70	5·6±0·25	12·3±0·36	8·0±0·26	10·1±0·19	6·2±0·22
B	16·0±0·89	8·8±0·53	7·5±0·26	15·0±1·00	6·2±0·42	5·3±0·38	3·4±0·14
C	16·5±0·96	8·5±0·48	7·7±0·16	14·8±0·11	6·7±0·16	5·3±0·32	2·6±0·15
D	18·0±0·63	11·5±0·57	9·6±0·32	23·1±1·49	8·9±0·07	8·2±0·58	5·0±0·13
E	17·2±0·50	10·0±0·32	4·9±0·28	22·2±0·41	8·4±0·72	6·9±0·55	4·4±0·21
F	13·2±0·49	6·7±0·49	4·4±0·35	19·7±0·53	8·8±0·55	8·7±0·19	6·8±0·29
G	9·0±0·40	6·8±0·79	4·4±0·21	18·6±0·63	2·7±0·16	3·2±0·09	2·4±0·13
J	8·1±0·31	6·2±0·89	5·7±0·39	15·3±0·47	3·7±0·35	2·4±0·18	1·8±0·08
K	10·8±0·45	6·3±0·70	5·5±0·33	21·0±0·71	11·1±0·22	10·5±0·49	7·7±0·24
L	13·7±0·67	8·6±0·40	7·1±0·30	21·2±0·71	21·5±0·73	17·1±0·32	15·4±0·39
M	12·0±0·86	7·8±0·50	5·5±0·31	14·3±0·46	3·8±0·11	2·4±0·23	2·0±0·22
N	13·2±0·49	8·9±0·35	6·0±0·30	17·4±0·20	4·0±0·19	2·6±0·11	2·0±0·43
nsprayed	0·7±0·30	0·8±0·17	0·3±0·08	0·2±0·04	0·8±0·08	0·3±0·17	0·6±0·17

(2) *Estimation of Blight Infestation.* Throughout August, hot and dry weather persisted and the potatoes on all plots suffered from severe aphis attack, causing a rapid yellowing of the haulm. On many plants, further discoloration resulted from honey-dew which attracted large numbers of Bibionid flies. Evidence of Blight infestation was not apparent in the plots until September 1st, when it appeared in all unsprayed plots, and isolated lesions were seen in several of the sprayed plots.

TABLE IX.

The Effects of Supplements upon Initial Retention.

First application.		Second application.	
Supplement.	Copper estimate.	Supplement.	Copper estimate.
1% Pet. oil; 0·1% sulphite lye	18·0±0·63	1% Pet. oil; 0·1% sulphite lye	23·1±1·49
1% Pet. oil; 0·025% sulphite lye	17·2±0·50	1% Pet. oil; 0·025% sulphite lye	22·2±0·41
0·2% Pet. oil; 0·005% sulphite lye	16·5±0·96	0·2% Cot. oil; 0·01% Agral S.R.	21·2±0·71
0·2% Pet. oil; 0·02% sulphite lye	16·0±0·89	0·2% Pet. oil; 0·01% Agral S.R.	21·0±0·71
0·2% Cot. oil; 0·01% Agral S.R.	13·7±0·67	0·2% Cot. oil; 0·02% sulphite lye	19·7±0·53
0·2% Cot. oil; 0·02% sulphite lye }	13·2±0·49	0·2% sulphite lye	18·6±0·63
Nil }		Nil	17·4±0·20
0·01% Agral S.R.	12·0±0·86	0·1% sulphite lye	15·3±0·47
0·2% Pet. oil; 0·01% Agral S.R.	10·8±0·45	0·2% Pet. oil; 0·02% sulphite lye	15·0±1·00
0·2% sulphite lye	9·0±0·40	0·2% Pet. oil; 0·005% sulphite lye	14·8±0·11
0·1% sulphite lye	8·1±0·31	0·01% Agral S.R.	14·3±0·46

Inspections of the plots were made on September 7th, 13th and 21st but, on the latter date, it was found impossible to distinguish, with sufficient ease in the field, between haulm withered as a result of the previous aphis attack or killed by Blight.

The estimations of Blight attack, which were made on the scale used in previous years (8), were too few to permit any conclusion concerning differences in fungicidal efficiency between the various treatments, although it was apparent that the unsprayed plots were far more seriously attacked that any sprayed plot.

DISCUSSION.

The Influence of the Supplement on Initial Retention. An approximation to the initial retention can be obtained from the copper residue figures at each sampling immediately following spray application. For the second application the figures will include the small residue from the first one, introducing an error which is reduced if the relative order be taken instead of the actual figure. In Table IX, the copper residue figures for July 19th and for August 8th are arranged in order, omitting spray treatments A, H and O, in which forms of copper other than the red cuprous oxide were used.

An outstanding feature of the results is the favourable effect on initial retention of the sulphite lye emulsion of relatively high petroleum oil content. This effect was not observable in the laboratory experiments in which the initial retention of the sprays containing sulphite lye emulsion was little different from that of water alone, and in which preferential retention of the solid phase was not found. The effect was, however, suspected from previous field trials, and in the results recorded in Table XII of the second paper of this series (8), the petroleum oil sulphite lye emulsion occupies a high position. The reasons for this divergence are obscure but it is possible that, as excess of spray was applied to the readily wetted potato foliage, viscosity factors enter into consideration. On the whole, the field results bear out the laboratory conclusion that the presence of oil tends to neutralize the unfavourable effect of the emulsifiers on initial retention. Thus, the sprays without oil are towards the base of the two columns.

The Influence of the Supplement on Tenacity. To derive a figure representing tenacity, the amounts of copper residue on sampling dates subsequent to spray application have been expressed in Table X as a percentage of the respective amounts determined on samples taken immediately after spray application. It is at once apparent that the tenacity figures before the date of the second application and those following show big relative differences. The treatments J and G exhibit the highest tenacities in the first two columns but are among the lowest in the remaining columns of Table X. This difference

TABLE X.

Tenacities of the Copper Residues.

Interval.	19.7.37 to 29.7.37.	19.7.37 to 9.8.37.	11.8.37 to 19.8.37.	11.8.37 to 1.9.37.	11.8.37 to 14.9.37.
Treatment					
A	44	44	65	82	50
B	55	47	41	35	23
C	51	47	45	36	18
D	64	53	39	35	22
E	58	28	38	31	20
F	51	33	45	44	35
G	76	49	15	17	13
J	77	70	24	16	12
K	58	51	53	50	37
L	63	52	101	81	73
M	65	46	27	17	14
N	67	45	23	15	11
Rainfall (inches)	0·22	0·25	1·86	1·94	2·53

may be associated, firstly, with the extremely low rainfall of the period prior to the second application, as shown by the figures for total precipitation during the respective time intervals indicated at the head of the columns. Secondly, growth of foliage after the first application tends to lower the general level of copper residues introducing a secondary factor, probably negligible in these trials, of the influence of the spray treatment upon subsequent growth. For these reasons it may be assumed that the tenacity figures prior to the second application do not truly represent the ability of the spray deposit to withstand weathering, an assumption borne out by a general resemblance between the order of treatment when arranged in accordance with the tenacity percentages and when arranged in order of increasing initial retention.

TABLE XI.

The Influence of Supplements on Tenacity.

Spray.	Supplement.	Mean tenacity figure.
L	0·2% Cottonseed oil ; 0·01% Agral S.R.	85
K	0·2% Petroleum oil ; 0·01% Agral S.R.	47
F	0·2% Cottonseed oil ; 0·02% sulphite lye	41
B	0·2% Petroleum oil ; 0·02% sulphite lye	33
C	0·2% Petroleum oil ; 0·005% sulphite lye	
D	1·0% Petroleum oil ; 0·1% sulphite lye	32
E	1·0% Petroleum oil ; 0·025% sulphite lye	30
M	0·01% Agral S.R.	19
J	0·1% sulphite lye	17
N	Nil	16
G	0·2% sulphite lye	15

If the tenacity percentages determined after the second application are arranged in order of their means, the treatments fall into the series given in Table XI. The order follows, in general, that which would be anticipated from the laboratory tests. The presence of oils has enhanced tenacity, the emulsifier in the sulphite lye emulsions countering the effect of the oil. No large differences are, however, observed with sprays of the same oil content but of different emulsifier content when oil and emulsifier are the same, e.g. sprays B and C, D and E. On the other hand, the laboratory conclusion that cotton-seed oil has a better "sticker" effect than petroleum oil is borne out in the field, spray L being above K and F above B. Further, the unfavourable influence of sulphite lye on tenacity is shown, though the effect is somewhat masked by the poor tenacity of cuprous oxide alone, a consequence of its relatively large particle size. It is of interest to note that the spray systems in which interaction between solid and emulsifier had occurred, i.e. the Agral S.R. emulsion, head the list. In these sprays the cuprous oxide-oil aggregates were so large that continued agitation during spraying was necessary to ensure the application of a uniform concentration. With spraying appliances of the type now generally used in this country, it would be impossible to recommend a spray of this physical character to growers.

PRACTICAL CONSIDERATIONS.

An important factor determining the character of dilute emulsions or emulsion-suspension systems recommendable for practical use is the requirement that it should be as simple as possible for the grower to apply such sprays always at a known and constant concentration. Either the dilute spray should be sufficiently stable to ensure that the effects of layering, creaming or precipitation in the spray tank are negligible or adequate agitation should be provided in the spray tank to overcome a localized concentration of the spray ingredients. The conditions for efficient agitation, and the power required, have been investigated by Smith (17) in connection with "Tank mixture" methods of using oil sprays, and it is evident from his results that spraying machines of the types in general use in this country are ill-equipped in this respect. For the time being, therefore, the only spray systems which can be recommended for practical use are those which have considerable inherent stability, a requirement which rules out those emulsifiers which interact strongly with and cause a marked flocculation of added solids. Of the emulsifiers examined in the present investigation, sulphite lye appears to be the most suitable from this aspect.

The two important shortcomings of sulphite lye as an emulsifier are, firstly, the lack of ready means of evaluating the emulsifying properties of the product. It is already so cheap that the dangers of adulteration would seem improbable,

but there is a possibility that material from different mills may vary in character. The importance of this disadvantage has been reduced, in the previous use of sulphite lye as a spray material, by recommending a high concentration, a procedure which has augmented the second disadvantage, namely, the deleterious effect of sulphite lye on the tenacity of spray deposits. It has been shown above that a reduction of the sulphite lye concentrate of the aqueous phase of emulsion may be made without marked effect upon stability or ease of emulsification, and it was decided to examine the variabilities between different samples of the product in order to see whether a reduced concentration was practicable. In the absence of simple chemical methods of evaluating the content of lignosulphonic acids and of the uncertainty concerning the worth of this estimation as a criterion of emulsifying properties, the interfacial tension of the solution against highly refined petroleum oil was determined by the drop-weight-volume method.

A micro-syringe containing the aqueous phase was connected with a ground glass tip dipping below the surface of the oil. The volume of drops of the aqueous phase formed slowly in the oil phase was measured. Because of the slowness with which the static value of the interfacial tension was reached, it was found necessary to curtail the time of drop formation to fifteen minutes. The interfacial tension was then computed from the equation:

$$\gamma_{\text{A.B.}} = \frac{V\,(d_1 - d_2)\,g}{r\,f}$$

in which V = volume of one drop, d_1 = density of aqueous phase, d_2 = density of oil, r = radius of tip and f is an empirical factor. The value of $r\,f$ was determined from the drop volume of benzene in water, the interfacial tension of which is known.

This method is open to the criticism that, as f is a function of r/V^3, a correction should be applied. But as the method does not give the static value of interfacial tension it seemed of little use to apply this correction.

Eleven samples of sulphite lye were first examined, each at a dilution of 1 part lye to 4 volumes of water (20 per cent.). Powder samples were first dissolved to give solutions containing 55·4 per cent. by weight solid matter, the mean solid content of the syrups examined. This solution was then diluted as above. Included among the samples were a number from one British source, each sample from batches received in different years from 1937 back to 1931. The interfacial tensions obtained were 12·67, 12·91, 13·51, 15·50, 15·94, 15·87 dynes per cm. Samples of German origin, one a powder, the second a syrup of gravity 1·30, gave 20 per cent. dilutions with interfacial tensions of 12·30 and 12·75 dynes per cm. respectively. Samples of powder and paste from Swedish mills gave similar interfacial tensions (14·35 and 13·44 dynes per cm.). Finally, a trade product sold under a proprietary name, but suspected of being

sulphite lye, yielded at 20 per cent. dilution, an interfacial tension of 14·88 dynes per cm.

There is, among these samples, no evidence of large differences in interfacial tension and all of them emulsified oils readily in the laboratory homogenizer. No samples reputed to be sulphite lye have yet been encountered which do not function as emulsifiers in this machine, so that it has not been possible to test completely the value of interfacial tension as a criterion of emulsifying properties and for the standardization of sulphite lye. The results do, however, suggest that the enhancement of concentration to cover the chance of inferior samples is unnecessary.

To determine to what extent a reduction of sulphite lye concentration for stock emulsion preparation is possible, interfacial tensions of dilute solutions of three of the above mentioned samples were determined. Two samples of British origin showing relatively large and small interfacial tensions at 20 per cent. were examined, together with one German sample. The results, represented in Fig. 2, indicate that although the interfacial tensions fall rapidly with increase of sulphite lye from 0 to 5 per cent., further increase in concentration lowers the interfacial tension only slightly. A reduction of sulphite lye to 5 per cent. on aqueous phase seems therefore to be possible without, as shown

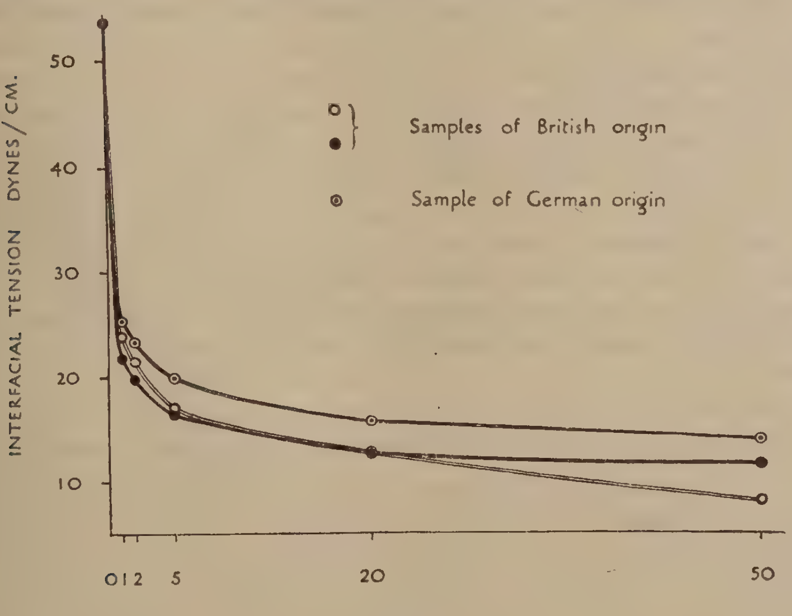

FIG. 2.
The Interfacial Tension of Sulphite Lye Solutions against Oil.

in Fig. 1, serious interference with the stability of the dilute emulsion, but with improved retention of solids added to the emulsion as shown in Table VI.

An important question for further consideration is whether it would be profitable in practice to develop spray machinery capable of the fool-proof application of emulsion-solid systems showing pronounced interaction. The work of Marshall and his colleagues (11) on flocculated arsenical sprays containing oils and soaps has indicated an improved insecticidal efficiency over non-flocculated arsenical preparations.* Similarly, Heuberger and Adams (9) have suggested that the flocculation of wettable sulphur suspensions by arsenical preparations results in a greater adhesion and toxicity per unit area of spray film. The laboratory work recorded above tends to show a greater retention (Tables III, IV and V) of sprays compounded with Agral S.R., which shows interaction with cuprous oxide, than with sprays compounded with sulphite lye, whilst an outstanding feature of the field trial results is the high copper residue of treatment L (see Tables VIII and XI), a mixture which shows pronounced flocculation.

SUMMARY.

The examination of those physico-chemical properties which determine the retention of spray fluids and the tenacity of spray deposits has been extended to sprays consisting of emulsions (liquid/liquid systems) and of added suspensions (liquid/liquid/solid systems). It is concluded that:

1. The initial retention of emulsions of sufficient stability for practical use is determined by the properties of the aqueous phase and is intermediate between that of the emulsifier solution alone and that of water.

2. The extent of preferential retention of the oil phase increases as emulsifier concentration is reduced and is dependent on the character of the emulsifier. Thus, lime casein emulsions exhibit preferential oil retention to a greater extent than sulphite lye emulsions of equal stability, a phenomenon which does not appear to be related to the wetting properties of the aqueous phase.

3. The initial and preferential retentions of emulsion-suspension systems are markedly affected by the extent of interaction between the emulsifier and

* In the more complete account of the investigation, published by Marshall (11a) since the above was written, it is shown that this improved insecticidal efficiency is due to the preferential retention of the oil-flocculated lead arsenate. Marshall concluded that this preferential retention appears to be dependent on the coating of the solid particles by oil, a phenomenon which he associated with chemical interaction between solid and emulsifier, and which may be strongly influenced by impurities or by other spray materials. To the change by which a suspended solid, initially wetted by the aqueous phase, becomes wetted by the oil phase he applied the term " inverted ", which seems an unfortunate choice, in view of the general use of this term for the change of oil/water to water/oil emulsions or vice versa. The terms " oil-flocculated " and " preferential retention " are therefore used above in place of " inverted " and " build-up " respectively, as used by Marshall.

the solid phase. This interaction, which though probably due to chemical reaction between the emulsifier and solid, is not always obvious from chemical data, results in partial or complete adsorption of the oil phase by the solid which is flocculated to large agglomerates.

4. If no such interaction occurs the addition of solid has no effect on either the initial retention of the emulsion or free oil retention. Neither has preferential retention of the solid phase been observed in such cases.

5. If interaction occurs, the stability of the emulsion is reduced, with consequent increase in the extent of preferential retention of the oil phase. Preferential retention of the solid phase then becomes apparent.

6. The tenacity of the deposits from emulsion-suspension spray systems is favourably affected by the presence of oil but may be adversely affected by the emulsifier. With sulphite lye, for example, the adverse effect of the emulsifier outweighs the favourable effect of the oil, which is greater with cottonseed oil than with highly-refined petroleum oil.

7. Owing to the necessity for using, in present spray machinery, sprays of high stability exhibiting but slow separation to layers of varying concentration, only emulsion/suspension systems showing little or no interaction between emulsifier and solid can be recommended for practical use. From this aspect sulphite lye appears to be the most suitable of the emulsifiers examined, and the disadvantages of its unfavourable effect on tenacity may be lessened by a reduction of emulsifier concentration. A comparison of the interfacial tensions between oil and solutions of miscellaneous samples of sulphite lye indicates but small variations in the properties of sulphite lyes from various mills. The reduction of emulsifier concentration in sulphite lye emulsions thus becomes possible in practice.

8. The advantages of emulsion/suspension systems exhibiting interaction and their practicability are discussed.

9. The main conclusions of the laboratory investigations summarized above were examined by a field trial employing cuprous oxide in combination with various oil emulsions for the control of potato Blight (*Phytophthora infestans*). Biological results were not available but a general confirmation of the laboratory conclusions was provided by analytical studies of the copper residues upon the foliage.

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PLATE I.

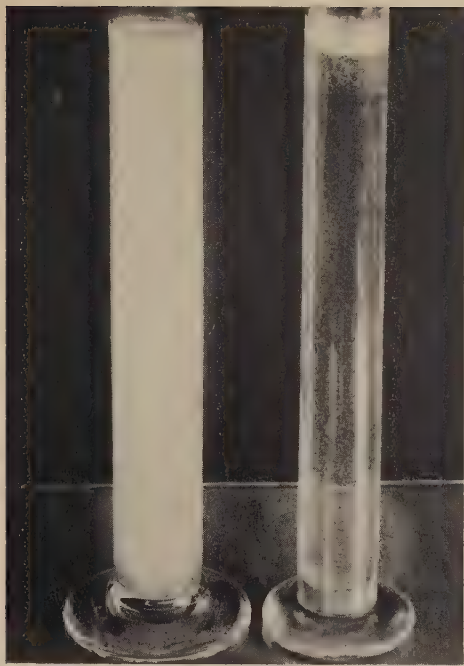

FIG. 1. THE COMPATIBILITY OF EMULSIONS WITH SOLID PARTICLES.
In cylinder on right—Agral S.R. as emulsifier.
In cylinder on left—Sulphite lye as emulsifier.
(See footnote, p. 19.)

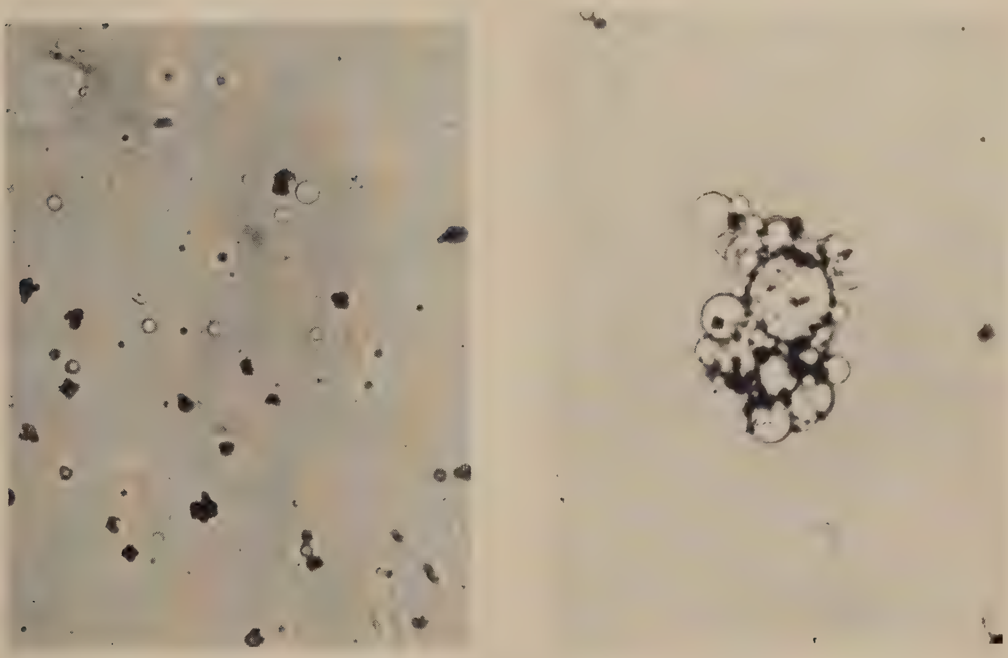

FIG. 2. MICRO-PHOTOGRAPHS OF EMULSION/SOLID SYSTEMS.
On right—Cuprous oxide-petroleum oil-Agral S.R.
On left—Cuprous oxide-petroleum oil-Sulphite lye.

STUDIES IN THE NON-SETTING OF PEARS

PART I*—FRUIT DROP AND THE EFFECT OF RINGING, DEHORNING AND BRANCH-BENDING

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Introduction.

It has long been recognized by English and other pear growers that certain varieties of good quality pears make excellent trees and blossom profusely, but are most irregular in setting their fruit. On the other hand there are a few commercial varieties which, when once they have come into cropping, usually set satisfactorily. This difference between shy- and free-cropping varieties has also been observed at East Malling. Records of the average total crop per tree of the free-cropping Conference and of the shy-cropping Doyenné du Comice during fourteen years show that Conference has yielded 286 lb. of fruit per tree and Comice only 44 lb., although both have blossomed freely.

Studies on this problem were begun in 1932, and references to them appear in Section II of the Annual Reports of the Station from that year onwards (1). Although partial explanations of this phenomenon have been offered by investigators all over the world, a full explanation for the conditions prevailing in England has not yet been supplied. Study of the literature suggested as the most promising lines of investigation: (1) weather conditions, (2) flower structure, (3) the shedding of immature fruits, and (4) cultural practices such as pruning, ringing and branch-bending.

Experiments carried out by the present writer at East Malling with three varieties of pear on quince rootstocks, dealing with fruit shedding and cultural practices only, are described here. Those dealing with other factors are reported elsewhere. Of the three varieties used, Conference is free-cropping, while Doyenné du Comice and Pitmaston Duchess are generally considered shy-cropping.

The So-called June Drop in Pears.

Flower shedding and fruit dropping have been studied by various workers. Thus, Dorsey (10) has studied the problem in plums, Bradbury (4, 5) in cherries, Harrold (13) in peaches, Detjen (8, 9) in apples, peaches and plums, and

* Parts II and III are being published in the East Malling Research Station Annual Report for 1937 (May 1938). All three parts are portions of a Thesis (presented in September 1937) approved for the Degree of Doctor of Philosophy in the University of London.

Murneek (26, 27) in apples. They found, in general, that the drop takes place in three distinct waves, though Murneek recognized four. He, however, quotes several authors who emphasize that there are only two waves in apples, and there is considerable diversity of opinion. He says, "By the 'First Drop' are commonly understood the first and second waves of shedding. . . . Either the third or fourth drop or both are usually designated as the 'June Drop.'" Howlett (17, 18) found only two drops in apples, the first soon after petal fall, and the second from the middle of June to the first week of July.

There appears to be no record of a study of fruit drop in pears, hence the first object was to find out when the June Drop takes place with this fruit.

Observations on Time of Dropping of Flowers and Fruits.

In 1936 two trees of Comice and one of Conference on each of three root-stocks, Quince A, B and C, were available and were left to open pollination. When all unfertilized flowers had fallen and the fruits had apparently set, viz. on June 12th, the number of fruits on four branches of each tree was determined, and a similar count was repeated at the end of each week till July 20th when dropping ceased. The periodical counts are plotted in Figs. 1 and 2.

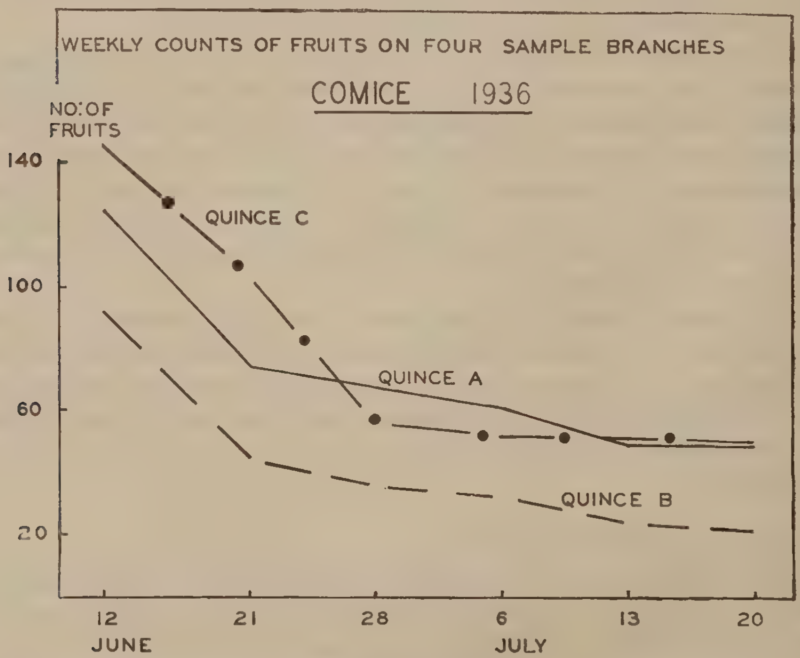

FIG. 1.

Graph of periodical counts of fruits on sample branches to show the June Drop period in Comice in 1936.

The interval between the first and second counts exceeds seven days, since actual dropping started only two or three days after the first count on June 12th. It will be seen that Comice and Conference behaved similarly. In both, the greatest drop had occurred by June 28th, though a further slight thinning went on till July 13th from the trees on Quince A and B. It was not possible to count the first drop of unfertilized flowers in this year.

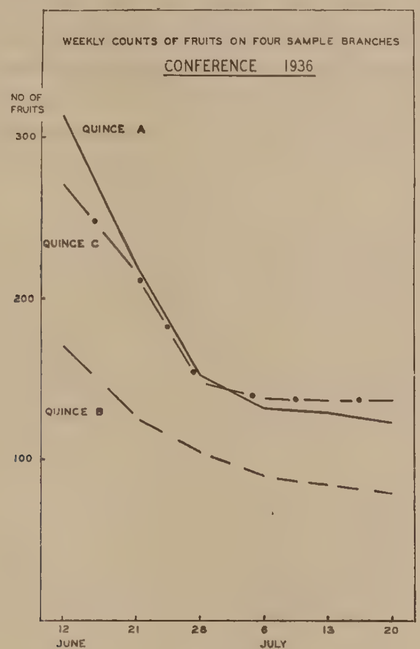

FIG. 2.

Graph of periodical counts of fruits on four sample branches to show the June Drop period in Conference in 1936.

Observations were continued in 1937. The same trees of Conference as in 1936 and one of Pitmaston Duchess on Quince C were selected. Observations could not be repeated on trees of Comice since they had no fruit buds.

The method of observation was altered in 1937, since it was desired to have records of the fruits dropped from the very start, and it was quicker and more accurate to count the fruits dropped than those left on the trees. The dropped fruits were collected from under each tree from immediately after petal fall until dropping ceased.

Fig. 3 shows two peak periods, or waves, of dropping in Conference on Quince A and B. The first, a very heavy one, started on May 13th (8-10 days after petal fall) and lasted till the 27th. The second, or June Drop, began after

an interval of two weeks, i.e. on June 9th, and lasted until the 24th. The Conference on Quince C tree, like the Pitmaston Duchess, had only one dropping period ; it began on May 13th and lasted two weeks.

Murneek (26, 27) has shown that when the first drop is very heavy, the June Drop may be very light or negligible. He also says there may sometimes be no second drop in an "off" year. All varieties of pears bore very heavy crops at East Malling in 1936 but had very little blossom in 1937, these trees were therefore then in an "off" year, hence the second drop was very light in Conference on stocks A and B and lacking in Conference and Pitmaston on Quince C.

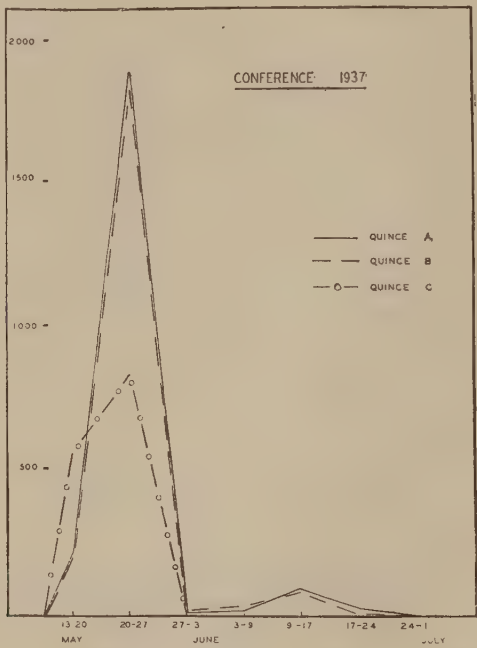

FIG. 3.

Graph of weekly counts of dropped fruits of Conference. Note the two waves of droppings.

From the 1937 data, two drop waves appear to occur in pears, viz. (1) a very heavy early one of non-fertilized flowers, and (2) a later slight drop of partially developed fruits. This second drop, though smaller than the first, is more conspicuous because of the larger size of the fruits. This is the real June Drop. The first drop in 1936 was not studied ; the second occurred mainly from June 13th to 28th. In 1937 it occurred from June 9th to 24th, being four days earlier. The flowers in 1937 opened about a week earlier than in 1936.

The 1937 records suggest that there are only two waves of dropping in pears, the second of which is a true June Drop. The number of fruits remaining on the trees in 1936 did not suggest more than one period of fruit drop.

Examination of Seeds in Dropped Fruits in 1936.

On the days on which the fruits remaining on the branches were counted, the dropped fruits under each tree of Comice were collected. The fruits dropped from the two trees on each stock were mixed and twenty fruits from each stock were taken. Four samples were then taken up to July 13th, when dropping had almost ceased. The fruits were cut and examined for the number of well-filled, plump seeds and for the shrivelled empty ones. The results are given in Table I.

TABLE I.

Mean number of plump and empty seeds per fruit found in weekly samples of dropped fruits during the June Drop period.

Sample : Date :	1 14-20/6/36		2 21-28/6/36		3 29/6-6/7/36		4 6-13/7/36	
Comice on :	Plump.	Empty.	Plump.	Empty.	Plump.	Empty.	Plump.	Empty.
Quince A ..	8·4	1·2	9·5	0·1	9·9	0·1	9·2	0·0
,, B ..	7·0	2·2	9·3	0·0	9·3	0·3	9·4	0·0
,, C ..	7·0	2·4	8·0	1·7	8·4	0·8	9·3	0·0

From this it is clear that the general opinion that the dropped fruits contain very few or no seeds is not supported. The number of plump seeds is very high in all samples, though less in the earlier than in the later droppings. Though it cannot be assumed that all plump seeds were necessarily fertilized, it seems reasonable to suppose that most of them were ; as will be explained in the next section, June Drop apparently does not result from lack of fertilization.

Size of Fruits and Time of Drop.

It is well known that most of the blossom borne by apples and pears falls off without setting ; relatively few flowers mature into fruit. Experiments were carried out in 1936 and 1937 to find whether the size of the fruit is important in determining its retention.

Three fifteen-year-old Conference trees on rootstock Quince B, of uniform growth, planted side by side in the same row, were chosen because it is a regular cropping variety and seemed otherwise an eminently suitable one for the purpose in view. Four random branches on each tree were marked off in four positions. The flower trusses on each branch were counted and, taking random sample numbers from " Random Sampling Numbers " (33), ten trusses well distributed over the branch were labelled. On April 29th, 1936, when

70 to 80 per cent. of the flowers on the trees had fully opened, each flower in all trusses (whether open or closed) was hand-pollinated with fresh pollen of Fertility—a compatible variety (16, 28). Unopened anthers from just expanded flowers were collected in a Petri dish the previous evening and kept at 20° C. overnight. Next morning all the anthers had burst and the pollen was ready for use. After pollination, every flower on each truss was tagged with an index letter. The top flower (sometimes called the King flower) was labelled A, the next below B, and so on. The flowers thus hand-pollinated totalled 928. Three weeks later, on May 19th, when the fruits had become more than 5 mm. in diameter, the maximum diameter of each was measured with vernier callipers. By this time fifty-eight fruits had already dropped, but they were too small for measurement or examination. Measuring was repeated on the corresponding day of each week till the crop was harvested.

As it was very important that all the measurements should be made on the same day, the maximum diameter was relied upon as the criterion for size, since in the early stages there were too many fruits to make more than one measurement possible in the time.

Samples of the fruits dropped from the marked trusses during the course of each week were collected, and the number of good and bad seeds in them determined. The results are given later (Table II).

It was clear from the figures that the fruits could be grouped according to the length of time they had stayed on the trusses. Those which fell during the week following the first measurement formed Group I, those falling during the week following the second measurement formed Group II, and so on. Fruits which fell in a gale shortly before picking time formed Group IX, while those finally picked formed Group X. The weekly measurements of the individual fruits in each group were totalled, and thus a mean for every week's measurement was obtained. The mean diameter of the fruit for each week in each group is plotted in Fig. 4; for Groups IX and X they are plotted up to July 21st only.

On May 19th the mean diameter of 116 fruits in Group I was only 5·8 mm. These were smaller than any in the other groups, and they fell within one week of the first measurement, i.e. before May 26th. Group II, consisting of 326 fruits, started with a mean diameter of 7·8 mm. on May 19th, but after one week this had decreased to 7·7 mm. and the fruits fell after May 26th. It must be noted here that in this group the mean diameter of the fruits in the beginning was 2 mm. greater than that of the fruits in Group I. Group III consisted of 212 fruits, which remained attached for a week longer than those of Group II, and were even bigger. The mean diameter at the start was 8·7 mm.; it increased slightly up to May 26th and by June 2nd it had decreased, after which all the fruits fell. The fruits in Group IV started with a greater diameter

still; they grew a little in the next week, remained stationary during the following one, and before falling had shrunk just as those in Groups II and III had done.

In the later groups, the differences between the initial measurements became less and less. Thus, the fruits in Groups V and VI started almost at the same point, though they were bigger than those in any of the previous groups. They

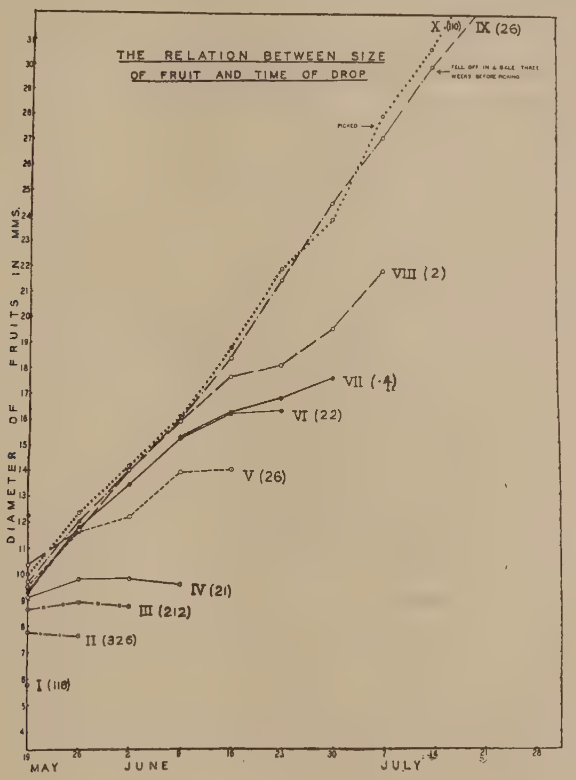

FIG. 4.

Curves showing the mean size of fruits in the Groups according to the time of drop in 1936. The number at the end of each curve indicates the total number of fruits in each Group, i.e. 116 comprise Group I and 110 Group X.

expanded more than 2 mm. in the next week, but after May 26th the differences between them became more marked, those in Group VI growing more rapidly than those in Group V. Before falling, the fruits in both groups almost stopped growing. The four fruits in Group VII behaved much like those in Group VI, and might really be included in that group, since the only difference

was towards the end, viz. on June 23rd, when Group VI had stopped growing. The fruits in Group VII increased in diameter by 0·6 mm., but since they fell off a week later than those in Group VI, they were treated as a separate group. These fruits were still growing shortly before falling, unlike those in the other groups so far described.

Group VIII, consisting of only two fruits, which fell on July 7th, was an exception to the rule. In the beginning these fruits were the largest, but in the following week they were overtaken in growth by those in Groups IX and X —which reached maturity—and were never again larger than them. They were growing rapidly before they fell, but they were the smallest of all the fruits remaining after June 30th. Groups VII and VIII can hardly be regarded as separate groups, since they consisted of only four and two fruits respectively ; however, since the fruits fell at different times, they have been separately grouped. The last two groups might also have been combined, since the fruits in Group IX were growing normally and would have been picked at the same time as those in Group X had they not been blown down by a gale early in September. Although they were growing at almost the same rate as those finally picked, there were very slight, but insignificant, differences in diameter, always in favour of the picked fruits, from the beginning to the end.

Most of the drop occurred before June 9th, and almost all dropping was over before the 30th ; only six fruits fell after that date.

The experiment was repeated in 1937, but only two of the three trees were used. The same branches were used as before, but the trusses were again marked at random, since all of the previous year's marked trusses did not bear blossom in 1937. Thus, in 1937 there were only eighty trusses. The same procedure was followed as in 1936. Hand-pollination with Fertility pollen was effected on April 24th. Blossoming was earlier, so that hand-pollination was also done earlier. The number of flowers pollinated was 584. The first measurement of fruits was made on May 18th. By this time twenty fruits had already fallen and were not included in the subsequent examinations. The measurements were repeated as in the previous year and the results up to July 12th are plotted in Fig. 5.

Fig. 6 shows the actual size of the fruits four weeks after pollination, and Fig. 7 the actual size of fruits remaining after the June Drop.

In general, the results of 1936 were confirmed by those of 1937. The fruits fell into six groups. The fruits in the various groups behaved strikingly like those of 1936. The smallest fell within a week of the first measurements ; those in the next group remained attached for a week longer, and so on. It will be seen that before falling off the fruits stopped growing or were even reduced in size as in 1936. Those marked " picked " in Fig. 5 were the largest of all on the tree at each weekly measurement.

It should be stated that the final percentage set of crop in 1937 (4·8 per cent.) was much less than in 1936 (11·4 per cent.). This was probably due mainly to unfavourable weather conditions (32).

The results show that the fruits that fall early are the smallest to start with, and remain the smallest at each week's measurements. Fruits hanging longer, and those which reach maturity, are larger to start with and grow much more

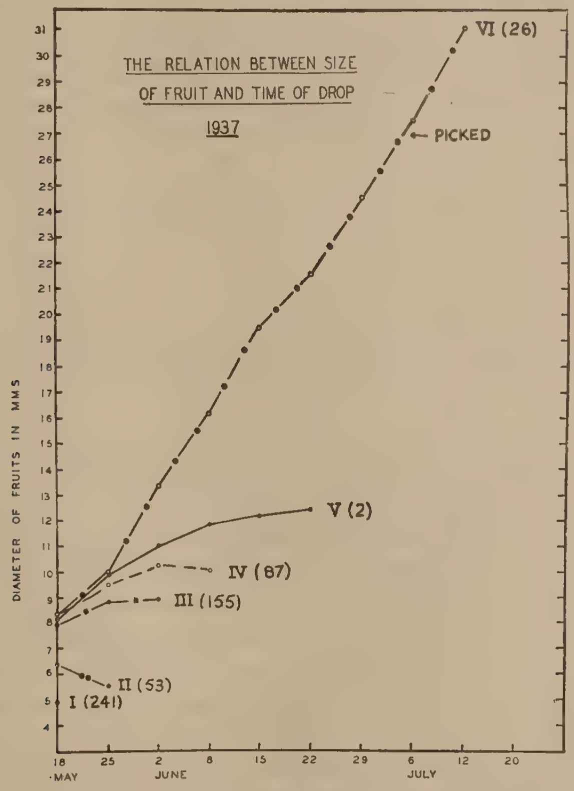

FIG. 5.

Curves showing the mean size of fruits in the Groups according to the time of drop in 1937. The number at the end of each curve indicates the total number of fruits in each Group.

rapidly every week than those which have a shorter life on the tree. In short, the smaller the fruit the shorter its life, and the larger the fruit the longer it hangs.

The differences in sizes may have been present even in the blossom stage, for other observations on size of flower in relation to fruit set have shown that within a given variety the larger the flower the better the set (32). Hence it is possible that flowers from which mature fruits are ultimately derived may have been the larger ones in the truss. This point requires further study.

Examination of Seeds in dropped and in picked fruits in 1936.

A rough attempt was made to determine whether the dropped fruits contained good seeds, in order to compare them with the fruits finally picked, as explained earlier (p. 43). In picked fruits, good and bad seeds could readily be distinguished by naked eye examination. The results are given in Table II.

TABLE II.

Mean number of good and bad seeds per fruit in weekly samples of dropped and a sample of picked fruits, from hand-pollinated trusses.

Sample:	I(20)*	II(20)	III(20)	IV(10)	V	VI(6)	VII(4)	VIII(2)	X(20) Picked.
Date:	19-26/5/36	26/5-2/6/36	2-9/6/36	9-16/6/36	16-23/6/36	23-30/6/36	30/6-7/7/36	7-14/7/36	22/9/36
Number of Good Seeds ..	7·7	8·8	9·0	8·3	—	6·8	9·7	8·5	3·5
Number of Bad Seeds ..	0·7	0·0	0·3	1·1	—	2·2	0·0	0·0	4·6

* Figures in brackets indicate number of fruits examined in each sample. No fruit could be collected for Sample V.

It will be seen that in all samples of dropped fruits, an average of seven or more plump seeds was found ; in picked fruits, on the other hand, the average number of apparently good seeds was less than half of this. This suggests that all the plump seeds in the dropped fruits were not fertilized. To clear up this point would entail laborious microscopical investigation which, unfortunately, the author was not in a position to undertake. He considers it reasonable to suppose, however, that most of the plump seeds in the dropped fruits were fertilized. At any rate, Detjen (8), who carefully examined the seeds in dropped apples, stated that the "vast majority of fruits falling in the later stages . . . showed evidence of ovule fertilization". He also showed that what looked like shrivelled and empty seeds actually contained fertilized egg cells, pro-embryos or embryos in various stages of development ; but these structures had ultimately aborted.

Thus, what were reckoned here as empty and shrunken seeds in picked fruits, may have contained fertilized embryos that aborted, perhaps as a result of competition for nutriment. At any rate, dropping could not have resulted from lack of fertilization, for the dropped fruits contained a larger number of plump seeds than those ultimately picked.

Position of the flower in a truss in relation to setting of fruit.

In order to find out whether the position of a flower in a truss had any relation to the percentage of fruit picked, the labelled flowers were arranged

in 1936 in the order of final percentage of set fruits that matured. This is shown in Table III.

TABLE III.

Relation between the positions of the flowers in a truss and the percentage of matured fruits (1936).

Serial No. of flower.	Total No. hand-pollinated.	Total No. picked.*	Percentage picked.
E	114	33	29
F	112	27	24
H	75	12	16
D	114	16	14
C	119	15	13
G	104	11	11
I	36	3	8
B	119	9	8
A	120	8	7
J	9	0	0
K	1	0	0

Significant difference in final percentage picked is equal to approximately 10 per cent.

* Fruits which fell during a gale just before picking treated as picked fruits.

As already mentioned, the topmost or King flower was lettered A, the one next below B, and so on, K being the lowest in the truss. Table III shows that the King flower (A) in Conference does not set better than the others, as is sometimes thought. Statistical analysis showed that flowers E and F, in the middle of the truss, set best and differed significantly in that respect from all the rest.

The observations were repeated in 1937 with the results shown in Table IV.

TABLE IV.

Relation between the positions of the flowers in a truss and the percentage of matured fruits (1937).

Serial No. of flower.	Total No. hand-pollinated.	Total No. picked.	Percentage picked.
D	80	6	8
E	80	6	8
B	80	5	6
F	79	4	5
G	64	2	3
H	33	1	3
C	80	2	3
A	80	0	0
I	7	0	0
J	1	0	0

The 1937 crop was so poor that the numbers of fruits set were too small to be analysed statistically, but there are indications that flowers D and E, in the middle of the truss, gave a better set than those in other positions. Not a single King flower (out of eighty) of Conference developed a mature fruit.

The King flower is sometimes thought to be the largest in the truss, but since it is in the centre and is closely surrounded by others, its corolla cannot fully expand, so that its full size is not readily discernible.

Effect of Certain Cultural Practices.

To ascertain whether non-setting in pears, i.e. the shedding of flowers and immature fruits, is a nutritional problem, experiments were made to change the normal distribution of nutrients. They consisted of drastic heading back (dehorning), ringing and the bending and tying down of branches.

Drastic dehorning.

Beneficial effects from dehorning were first recorded in England when certain growers severely headed back some non-fruiting Doyenné du Comice trees and top-grafted them with a better setting variety. They obtained a great increase in crop on the branches of Comice that remained below the graft union in the year of operation, and explained this result as being due to transfusion of sap from the new scions of the better setting variety. This appears to be unlikely, since the scions could hardly have become established so quickly as to have had such an immediate effect, even if an influence of this kind were known to exist. The increase was much more probably a direct result of dehorning, since the removal of substantial portions of the trees would leave a relatively greater amount of nutrient for the remaining parts than was previously available.

Alderman and Auchter (3) found that heavy dormant pruning of fifteen-year-old bearing apple trees increased fruit production. Heinicke (14, 15) found that the percentage of apple blossom set was increased when the branches were pruned back in the spring just before flowering time. Kains (19), Knapp and Auchter (21) state that heavy pruning of middle-aged trees, especially of Bartlett and Anjou pears, resulted in an increased set of fruit. Chandler (6) states that growers in New York have induced Anjou pear trees that were dropping all or nearly all of their bloom every year, to retain good crops by pruning them severely. In England, Pitmaston Duchess blooms very heavily every year, but generally sets only an extremely small percentage of fruit. Hence this variety was selected for the dehorning experiment.

Eight fourteen-year-old Pitmaston Duchess trees on Quince rootstock A were available. Since they had previously been used in a pruning trial, they were not all uniform in size, but it was possible to arrange them in pairs of similar

size and vigour, and four such pairs were employed. One tree of each pair was dehorned, the other left untreated as a control.

On March 19th, 1936, all the main branches of the trees to be dehorned were sawn off at the top of seven- or eight-year-old wood. The cut was made back to a lateral branch or to a spur, in order to keep the tree balanced and to remove approximately half of the fruit-buds. After dehorning, the cut ends were smoothed and covered with white lead paint. Fig. 8 shows a tree before and Fig. 9 the same tree after dehorning.

The lengths and the ages of the portions of wood cut off were determined. It was found that the lengths varied from $5\frac{1}{2}$ to 11 ft., while the ages were from 6 to 9 years, the most common being 7 to 8 years.

The fruit-buds on the parts removed and those left on each tree were counted separately. The total number on each control tree was also determined. In three of the four dehorned trees very nearly half the fruit-buds were removed, but from the fourth (No. 17/14) about two-thirds were removed, probably because this tree had less wood growth than the others.

At picking time the number of fruits from each tree was counted and the percentage set (per 100 fruit-buds) was calculated. The results are given in Table V.

TABLE V.

Number of fruit-buds and number and percentage of fruits picked on dehorned and control trees.

Dehorned.					Control.			
Tree No.	No. of fruit-buds removed.	No. of fruit-buds left.	No. of fruits picked.	% Picked.	Tree No.	No. of fruit-buds on the tree.	No. of fruits picked.	% Picked.
17/2	2149	1800	206	11	17/4	2227	51	2
17/12	1396	1192	119	10	17/10	3899	55	1
17/14	1026	550	38	7	17/16	3083	124	4
21/7	1487	1228	54	4	21/9	1321	10	1
		Mean =	104	8		Mean =	60	2

It will be seen that the percentage set on dehorned trees was in every case higher than that on the control trees. On statistical analysis the differences were found to be significant. Not only was the percentage set higher but the mean number of fruits picked from the dehorned trees was also greater than from the controls.

In 1937 the fruit-buds were again counted, but owing to an abnormally wet spring, no fruit was set on any of the trees. There was, however, a definite effect on blossom production in 1937.

Table VI shows that all but one of the dehorned trees bore far fewer fruit-buds in 1937 than in 1936, but that there was no reduction in the controls. This shows that even the small average crop of 104 fruits on dehorned trees in 1936 put them in an "off" year in 1937, and indicates that dehorning is likely to be followed by an "off" year.

TABLE VI.

Number of fruit-buds on the dehorned and the control trees in 1936 and 1937.

Dehorned.			Control.		
Tree No.	No. of fruit-buds in 1936 (after dehorning).	No. of fruit-buds in 1937.	Tree No.	No. of fruit-buds in 1936.	No. of fruit-buds in 1937.
17/2	1800	871	17/4	2227	3472
17/12	1192	241	17/10	3899	3962
17/14	550	590	17/16	3083	—*
21/7	1228	376	21/9	1321	1387

* Tree grubbed.

Since dehorning in 1936 had resulted in a definitely better set in the same season, the experiment was repeated with another series of trees in 1937.

However, since the weather conditions that season were unfavourable to the setting of Pitmaston Duchess, practically no fruits matured and hence no conclusions could be drawn. From an experimental point of view, it is interesting to note that the method of dehorning proved fairly accurate. In five trees out of seven so treated in two successive seasons, approximately half the fruit-buds were removed from each tree by dehorning—which was the result aimed at.

Ringing.

Ringing, i.e. the removal of a circular band of bark down to the wood from stems or branches, as a means of increasing fruit production in grape vines, has been practised for centuries in Europe. It has also frequently been employed with fruit trees, especially to promote early bearing in "filler" trees in commercial plantations, and also to induce unproductive, over-vegetative trees to fruit.

While it is generally accepted that ringing causes fruit-bud formation in hard fruits and fruit production in the following year, there is considerable disagreement as to its effect on the set of fruit in the year of ringing.

Thus, Swarbrick (30) says that ringing results in increased flower-bud formation. The factors controlling the setting of apple blossoms are quite different from those governing their formation ; and where there is abundance

of blossom but no set of fruit, it is not advisable to ring the trees. Gourley and Howlett (12) say that ringing has not been suggested as a cure for trees that blossom and fail to set fruit, but only for those of sufficient age that fail to form fruit-buds.

Heinicke (15), on the other hand, says that ringing about the time of blossoming has invariably increased the set of fruit. Again, MacDaniels and Heinicke (24) say that ringing is often very effective in inducing apples, such as those of the Winesap group, which tend to produce abnormal and weak flowers, to set fruit. Seabrook (29) says that pears that have flowered profusely but have not set fruit, have been induced to do so by ringing, when the failure was not due to lack of pollination. Morton (25) agrees that ringing is now generally recognized as a method of improving fruit production on shy-bearing trees, and Wallace (36) says that ringing will often increase fruit setting in unfavourable seasons.

Several theories are mentioned by Akenhead (2) as underlying the physiological effects of ringing. In the absence of knowledge as to the exact function of the phloem elements and of the outer wood vessels, there can be no certainty on the matter at present, but it is thought that, with slight variations, the views of Kains (19) may be taken as representing those of most workers. According to him, the theory of the operation is that the removal of a ring of bark, including the cortex and the phloem, at the period of most vigorous growth, does not hinder the upward passage from the roots to the leaves of raw sap through the outer rings of the wood, but does prevent the downward distribution of assimilated food through the cortex and the phloem below the wound. The effect is to cause an extra amount of reserve material to be stored in the upper parts of the plant for the production of fruit-buds.

As to the effect of ringing on the setting of fruit, Chandler (6) says that ringing increases the amount of carbohydrates relative to nitrogen and may have other influences. Possibly fruit setting is influenced by some organic nitrogenous compound, and ringing, by preventing this from moving backwards, may increase the amount available for the young fruit.

Unpublished results of ringing experiments with Beauty of Bath apples carried out at East Malling have indicated an increased set of fruit in the year of ringing. A ringing trial was also made with pears, in 1932, but it had no such effect. Ringing was again carried out with pears in 1936, various modifications being introduced. Fourteen fourteen-year-old Pitmaston Duchess trees on rootstock Quince A, all in the same row, were employed. They varied in size owing to differential pruning in their earlier years. They were divided into two groups—one of eight comparable trees not previously pruned, the other of six trees which had undergone "regulated" and "modified leader" pruning previously.

As suggested by Heinicke (15), ringing was done just before flower opening. Both stem and branch ringing were tried. Instead of removing a complete ring of bark, two half-rings were removed and the cambial tissue exposed, as described by Morton (25). The rings were kept open and adhesive tape or other binding was not applied.

1. *Stem ringing*. Four of the eight trees in the first group were ringed on April 9th, 1936, the other four being left as controls. Two half-rings, one higher on the stem than the other, in opposite positions, were cut with a "Gardener Ringer". The distance between the upper and the lower half-ring was 10 cm. Each upper half-ring was cut 5 cm. below the usual swelling on the trunk from which the main branches arise. The width of each ring was 2 cm.

2. *Branch ringing*. Six branches of approximately equal diameters were selected on each of the six trees in the second group. Three trees were left as controls. Alternate branches on each of the other three trees were ringed on April 9th, leaving the other branches as controls. Two half-rings were made as in the stem ringing, but with a knife. The distance between the rings was 5 cm. and their width was 1 cm. The remaining branches on the same trees and the selected branches on the control trees were marked with white paint to indicate the position at which the upper ring would have been cut if they had also been ringed. While it was realized that the unringed branches might neutralize any effect on the ringed branches, it was thought desirable for purposes of comparison to leave control branches on the same trees, as well as on other unringed trees.

The following records were taken: (1) In the stem-ringing trial, since the trees were very large, all the fruit-buds on two sample branches on two sides of the tree were counted.

(2) All the fruit-buds above the rings on the ringed branches were counted, and those above the mark on the unringed branches of the treated and untreated trees. When the crop was harvested, all the fruits picked from each of these branches were counted.

On analysis, the figures showed a very wide variation in the percentage of fruit set, even on unringed branches. It varied from 0·7 to 11·2 per cent. and was most striking on the ringed branches, so that no significant conclusion could be drawn. One of the stem-ringed trees set only 0·2 per cent., another 15·4 per cent.; the former figure was much lower than the mean of the non-ringed trees, while the latter was four times as great.

Since there was no consistent effect of ringing in 1936, the rings were not allowed to close and they were re-cut on November 9th. The control trees of both branch and stem-ringing trials were used for a dehorning trial in 1937.

Records of fruit-buds and fruit set were again taken on the treated and untreated branches of the branch-ringed trees and also on the two sample

branches on each of the stem-ringed trees. Practically no fruit was set in 1937 owing to unfavourable weather, but Table VII shows that all but three of the ringed branches bore more fruit-buds than the unringed ones on the same tree.

TABLE VII.

Number of fruit-buds on ringed and unringed branches in 1937.

Tree 13/2.		Tree 13/6.		Tree 13/12.	
Ringed.	Unringed.	Ringed.	Unringed.	Ringed.	Unringed.
428	143	432	211	448	581
312	203	285	322	332	280
268	280	265	164	442	302

General mean for the ringed branches = 357.
,, ,, ,, ,, unringed ,, = 276.
Significant difference (when $P = 0{\cdot}05$) = 95·12.
,, ,, (when $P = 0{\cdot}1$) = 78·34.

Statistical analysis showed that the difference in favour of ringed branches was not quite significant (based on $P = 0{\cdot}05$), but the odds are 9 to 1 in favour of significance.

Since no control tree was left in 1937 for comparison as to the fruit-buds produced on the stem-ringed trees, the fruit-buds on these trees in 1937 have been compared with those borne by trees in 1936 (see Table VIII).

TABLE VIII.

Total number of fruit-buds on two sample branches of ringed trees in 1936 and 1937.

Tree No.	No. of fruit-buds in 1936.	No. of fruit-buds in 1937.
13/1	1007	1776
13/5	2117	2698
13/9	904	1152
13/13	748	613
	Mean = 1194	Mean = 1534·75

Significant difference = 316.

Table VIII shows that these trees bore significantly more fruit-buds in 1937—the year following ringing—than in 1936.

Even when the fruit-buds borne by the ringed and unringed branches in two years were compared, it was found that almost all the ringed branches produced many more fruit-buds in 1937 than they did in 1936, while the unringed branches did not.

The figures for pears therefore show that ringing definitely increased the number of fruit-buds in the following year, but they do not show any consistent effect on the set of fruit—at least of Pitmaston Duchess—in the year of ringing.

Tying down of branches.

Bending or tying down branches to induce early fruiting in young orchards is a very old commercial practice. It was known centuries ago that young trees could be induced to bear heavy crops by suspending heavy weights from the ends of their branches. Langley (22), writing in 1729, says: "The nearer branches are laid to an horizontal position the velocity of the sap is the more retarded, and the nearer to a perpendicular position, the more freer, therefore branches that are inclinable to luxuriancy may be checked by being nailed horizontally and those that are weak helped by being nailed perpendicularly."

Kinman and Magness (20) state that the system of tying and spreading branches has developed in the Pacific coast region of America, especially in California, where it has been substituted for pruning. Tufts (34) describes how Mr. Caldewell in California obtained very early fruiting on young Bartlett pear trees by adopting this so-called Caldewell System of pruning. Tukey (35) says: "Tying trees down checks growth and causes early fruiting."

The principles governing this system are variously explained by different authors. Thus, Tukey mentions the theory that "the shoot which has the ascendency over the others develops an inhibiting substance which passes down the shoot and inhibits the development of the others.* If then a branch is bent down so that the end bud is at a lower position than others on the shoot then it can be readily appreciated that the other buds may tend to take the lead and full energy of growth may be developed along the branch in an entirely different way than normal, yet without reduction of leaf surface through pruning. This is the theory upon which manipulation depends."

Chandler (7) says: "Bending branches downwards tends with young trees to cause fruit-bud formation on the parts bent downward. . . . When the branch is bent downward the end no longer has a dominant position and growth is checked; carbohydrates may thus be caused to accumulate before the buds, at the newly dominant position at the top of the curve, begin to grow and use carbohydrates. If the bending is used as a substitute for severe cutting back of the top to shape it, more leaves will be left to evaporate water and to form carbohydrates and fruit-bud formation would be encouraged."

Dotti, F. (11), concludes from his experiments that bending of branches can partially take the place of pruning. He considers that normal drastic pruning, while necessarily cutting down net increment, tends to promote excessive vegetative growth and to postpone cropping. By bending the branches, instead

* This is actually the Loeb theory, quoted by Barker and Lees, Long Ashton Ann. Rep., 1919.

of cutting, it is ensured that they are still in a position to carry on the work of assimilation. Moreover, bending does not modify the top:root ratio, but merely tends to direct the flow of sap towards other parts of the top. He found that over a period of four years, bent trees gave a significantly greater crop than normally pruned trees.

MacDaniels and Heinicke (23) experimented with upright growing apples like Northern Spy and with Kieffer pear trees. Within two years of bending, the yields were enormously increased as compared with unbent trees.

One of the most obvious reasons why tying down branches has been suggested for increasing fruit production and one which has not been emphasized by the authorities quoted above, is increased exposure to light. Tying down branches opens up the tree ; there is no shading of the lower branches, and under the improved light conditions the tree is rendered more fruitful.

To see how far this system could be applied to increase fruit setting in pears, an experiment was carried out on mature trees of Pitmaston Duchess. Five sixteen-year-old trees, two on Quince rootstock E and three on C, were available. One on E and two on C were tied down on March 17th, 1936, leaving two trees as controls, one on each of these stocks. The main branches were bent down and tied to pegs in the ground, the branches being inclined at an angle of about 45°. Pieces of sacking wrapped round the branches under the strings prevented injury to the branches. (See Fig. 10.)

Since the trees were too large to permit the counting of all the fruit-buds on each, four branches in four positions on each tree were marked and the fruit-buds on each were counted separately. The 1936 crop on each branch was harvested separately in order to obtain the final mean percentage set for each tree. The total number of pears picked from the whole of each tree was also counted. The results are assembled in Table IX.

TABLE IX.

Comparison of crop from Pitmaston Duchess pear trees where branches were tied down and left naturally.

Final mean percentage fruit set and total crop.

Pitmaston Duchess.		Tied.		Not tied.	
		Mean % set	Total crop.	Mean % set.	Total crop.
	Tree		No.		No.
On Quince C	1	8	395	12	341
	2	19	642		
	Mean	13	518·5		
	Tree				
On Quince E	1	9	355	7	281

It will be seen that the percentage set on the tied down trees on Quince C was less in one case, but much greater in the other, than on the control tree. The mean on the two tied trees was a little higher than the control. On Quince E the tied tree also gave a higher percentage set than the control. Every tied down tree gave a larger total crop than the corresponding control. Owing to the small number of trees used, these differences in favour of the tied trees cannot with certainty be regarded as significant. Fruit-bud counts were made in 1937, but owing to abnormal spring weather no fruits set.

A similar experiment was also tried on young six-year-old Comice trees which had not yet borne fruit-buds. In the second year, more fruit-buds appeared to be formed on the tied down trees than on the controls, but owing to the variability of the material, this was not statistically significant.

GENERAL DISCUSSION AND CONCLUSIONS.

The main cause of fruit dropping did not appear to be lack of fertilization, since examination of dropped fruits showed that they contained a sufficiently large number of apparently normal seeds. Withering or shrinkage of fruits before falling, and the fact that the drop of smaller fruits persisted throughout the season, suggested that competition for food and water might be concerned. The larger fruits, being possibly in a better position, drew more nutriment from the tree and hence were able to persist longer than the smaller ones. It has already been pointed out that it was the flowers in the same positions in the truss each year which gave the best set, and this suggests a connection with the distribution of food and water.

Weather conditions, including rainfall and soil moisture content, have been studied in this connection,* and whilst there was a tendency to soil dryness at the time of fruit dropping, it was only slight. At any rate, it is possible that a general demand for water at this critical period might have encouraged fruit dropping. Evidence also showed that a greater percentage of fruit set on the south or sunny side of the tree, which might offer better growth conditions.

As to the effect of the cultural practices (dehorning, ringing and bending) carried out, it was found that the result of removing nearly half the top of the tree was a significant increase in the set of fruit. This suggests that more food was available after dehorning, or that there was a better balance in the altered shoot : root ratio.

On the other hand it was found that ringing, which is known to prevent the backward movement of food and cause its accumulation above the ring, resulted in increased fruit-bud formation, but no consistent improvement in the

* See Part II, published in the East Malling Annual Report for 1937.

set of fruit. The problem with shy-cropping varieties is not so much the lack of blossom as the failure of such blossom as the trees produce to set.

The bending and tying down experiments, both with young and established trees, gave very variable results.

The observations made strongly suggest that the problem of the non-setting of fruit in pears is a nutritional one, and this is supported by the fact that trees on rootstock Quince C gave the greatest percentage set of fruit (32). Hence injections of water, urea and urea plus potassium phosphate were made into a tree (30). This was the first experiment of its kind with pears, and in the absence of knowledge as to the best substance to inject and the optimum concentration, it was perhaps not surprising that a heavy drop of fruit took place. The experiment provided a useful guide as to the required strength of solution for future trials, but did not shed any light on the nutritional aspects of the problem.

SUMMARY.

Experiments were carried out during two years to find the causes of dropping of pear flowers and fruits and to see whether dehorning, ringing or branch bending would throw any light on this problem. One free-cropping variety (Conference) and two shy-cropping varieties (Doyenné du Comice and Pitmaston Duchess) were employed, and the results were as follows:—

1. There are two waves of dropping, (i) a very early shedding of non-fertilized flowers, (ii) a late, and by comparison, light, dropping of partially developed fruits, popularly known as the June Drop.

2. The main cause of June Drop did not appear to be lack of fertilization, since plenty of apparently healthy seeds were found in most of the fruits dropped.

3. The size of the individual fruit was found in both years to be correlated with its length of life on the tree. The smaller the fruits, the shorter their life; or, the larger the fruits, the longer they remained attached, thus indicating that the dropping of fruits was due to competition for nutriment.

4. Drastic dehorning, i.e. cutting the main branches back to eight-year-old wood, definitely increased the set of fruit in the year of treatment; unfortunately its effect in the following year could not be followed, owing to abnormal weather conditions preventing any fruit setting.

5. Ringing gave no consistent improvement in the set of fruit, but definitely induced increased fruit-bud formation.

6. Bending over and tying down the main branches of both young and established trees gave rather variable results, both as regards the set of fruit and the formation of fruit-buds.

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Fig. 6.

Actual size of fruits four weeks after pollination.

FIG. 7.

Actual size of fruits remaining after the June Drop.

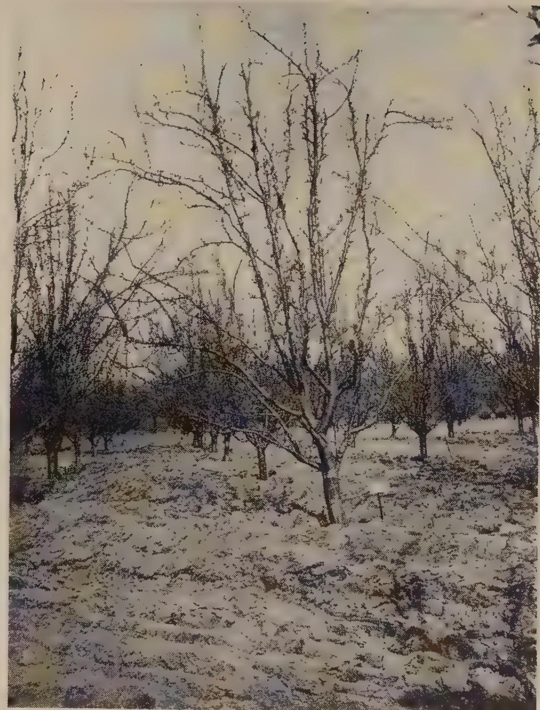

Fig. 8.

Pitmaston Duchess *before* dehorning in 1936.

Fig. 9.

Pitmaston Duchess *after* dehorning in 1936.

FIG. 10.

Method of bending and tying down branches of an established Pitmaston Duchess tree.

STRAWBERRY CULTIVATION STUDIES. I.

THE PERFORMANCE OF INDIVIDUAL PLANTS OF CLONAL FAMILIES

By W. S. ROGERS and JOYCE L. EDGAR

INTRODUCTION.

In the large scale field trials of strawberry strains* carried out at East Malling from 1927 to 1930 (1), a considerable amount of plant-to-plant variation was observed amongst plants undergoing similar experimental treatment. Such variation was visible to an even greater degree in many commercial plantations.

It was widely suggested that the frequent occurrence of weak plants and, indeed, in some cases, the deterioration of whole stocks, was due to the fact that their vitality had become weakened by taking too many runners from the parent plants. It was argued that the first-formed runners† were naturally strong and that those formed later were clearly smaller and weaker. Therefore, in order to get the best results, only first runners, i.e. the earliest to form on a stolon, should be used, and only a limited number of these be allowed to grow from each parent.

Little experimental evidence was then available as to the performance of different classes of runners taken from the same parent. Darrow (2), in 1929, in a study of the formation of runners, noted that they might be formed from as early as May to as late as October, and he showed that those formed early produced more fruit in the following summer than those formed late.

Ball (3), in 1925, at Long Ashton, compared the performance of runners limited to three "first runners" per parent with that of unlimited runners, and found that the former were more vigorous and fruitful than the latter. This will be discussed later.

In October 1930 it was decided to try to obtain healthier and more uniform planting material by starting afresh and raising clones‡ from selected healthy parents, as had already been done at East Malling with fruit tree rootstocks, black and red currants and raspberries. It was decided, at the same time, to obtain detailed information on differences in runner performance by following out the behaviour, over a series of years, of a number of individual strawberry

* Strains, as used here, means different stocks of the same variety.

† In this paper the common usage by which the young plants themselves are called runners will be followed. For the creeping stem on which the runners are produced the botanical term stolon will be used.

‡ A clone is a race of plants propagated vegetatively from one individual parent plant. In this paper the term family is used to denote the group of runners produced by a single parent plant.

plants of known origin, from the time of their formation as runners onwards. It was thus hoped to find out the relationship between plant performance and such factors as time of formation of runner, position on the stolon, size at planting time, incidence of disease, etc., and to observe the maintenance or decrease of vigour under known conditions.

The investigation consisted of two main trials, as follows:—

Trial I. The raising of about 1,000 plants from runners of known time of formation and position on the stolon, and testing them individually for vigour and cropping for four years.

Trial II. Similar propagation of runners from specially selected plants raised in Trial I, and testing for three years.

A similar batch of material for a third trial was also raised from selected plants raised in Trial II, but as the results of Trials I and II were confirmatory, it was considered unnecessary to repeat the work further.

TRIAL I.

Methods and Material.

Suitable material was to hand, in three families of Royal Sovereign plants, propagated from individuals selected from the original three strains used in previous trials (1). From these three families twelve plants were selected as parents for the new trial. These were planted out 6 ft. by 4 ft. apart in October 1930. Later, when the large number of runners produced by the layering method adopted was seen, the number of plants was reduced to six. All were of good size, healthy and vigorous.

All blossom trusses that appeared in May 1931 were removed, to encourage runner formation, and the first runners were ready to root by June 9th.

Each week subsequently the plants were inspected, and all runners ready to root were pegged down with wire staples carrying metal labels bearing the serial numbers of the runners. At the same time a plan was made of each main stolon, showing exactly where and when each runner arose. From this plan the runners were afterwards divided into various classes for summarizing purposes, as discussed later. No restriction was placed on runner formation.

It was found that, with the parents well spaced, the runners systematically pegged down, and the ground kept free from weeds, runner production proceeded at a surprising rate. By October 20th the six parent plants had produced 1,031 rooted runners, an average of 172 per plant. The appearance of a typical family is shown in Fig. 2. This is the family of a two-year-old plant. One-year-old plants were similar but had smaller families. The runners in this trial covered the ground available as closely as in a commercial runner bed. In Trial II they had rather more room.

The Trial I runners were lifted, washed and weighed in the laboratory during the period November 2nd to November 5th, 1931, and notes were made on the rooting and vigour of each runner; immediately after this the runners were planted out in the experimental area.

Twenty-four of the runners, representing various classes, were chosen to develop as parents for the production of runners with which to start Trial II. These were planted 12 ft. apart to give full scope for runner production. The rest were planted in rows 30 in. apart, at a distance of about 15 in. in the rows, for fruit and vigour records. The runners of each separate stolon of each parent plant were planted consecutively, in numerical order. No attempt was made to randomize the progeny of individual plants or stolons, owing to the variable numbers of runners from each. Fortunately the frequent repetition of the various classes of runner all over the experimental area ensured good distribution.

Cultivation was kept equal over the whole area by assigning all the hand work to one careful workman. Insect pests were combated as far as possible by sprays recommended by Dr. A. M. Massee. Perfect control of mite and aphis on a large scale is not yet practicable, however, and outbreaks of mite and aphis occurred from time to time. Nevertheless, the plants kept up very satisfactory vigour until the end of 1935, as the records show.

Full records of individual plants were made for the next four years, i.e. 1932-35. A health survey was made at the beginning, middle and end of each season, with certain additional surveys; vigour measurements were made each spring and also in the autumn of some years; blossom records were made in the first spring, and records of number and weight of fruits on each plant were made in the three following years.

The health surveys were usually made by two or more members of the staff together, so that identification of virus disease or other abnormal symptoms could be checked. The vigour records consisted of measurements of height and spread of plant. Spread was measured across the row, and height from ground level to the top of the highest leaf. Dead leaves were excluded. Special measuring rods were employed, graduated at first in 5 cm. units; later, 1 in. graduations were adopted, since the latter gave greater accuracy and were still quite easy to read. An illustration of the measuring method was given in a previous paper (1).

For blossom records, the trusses were assessed as large, medium and small, to which were assigned 3, 2 and 1 marks respectively. These were added to give a "blossom figure".

To obtain the cropping records special methods were necessary, since the fruits of about 1,000 plants had to be picked, counted and weighed in the field for each individual plant within a day. The produce of each plant was picked

into a separate 1 lb. chip basket, placed beside it, bearing the plant number. The baskets were carried to a table beside the plot, where the fruits were counted and weighed on hanging spring balances protected from the wind by screens and having detachable interchangeable aluminium pans. For speed and accuracy, special graduations marking 5 gm. units were used, as this usually gave a one- or two-digit figure easy to read and quick to write down. In the summaries in this paper the figures are converted to grammes.

The thousand or so plants at the start became gradually reduced as individuals showing disease were removed. Even so, the work of maintaining individual plant records was very great, particularly with the fruit records. An average of eight pickings were made of each year's crop, and this involved a total of some 40,000 counts and weighings. There were also over 20,000 records on the vigour and health of these plants of known origin. Thus a vast amount of data were secured, which have had to be drastically summarized to bring out the points of most importance. This has been done by dividing the plants into various classes, and obtaining the means for each class.

Classification of Runners.

The runners were, of course, automatically divided into time-of-formation classes of one week. Their further subdivisions referred to primary, secondary and lateral, according to their positions on primary, secondary and lateral stolons. The runners on each stolon were divided again into 1st, 2nd, 3rd, etc., in order of formation. This classification is illustrated in Fig. 1, which is a diagram showing the time and method of origin of the 122 runners formed by Plant D. This plant, having a relatively small number of runners, has been chosen for the sake of simplicity, but it gives a good idea of the origin and distribution of the various types of runner. Stolon 3 is a good example on which to follow out the explanation given below.

Primary runners were those formed on stolons radiating directly from the parent plant, and their direct continuations, and were given letters A, B, C, etc. These stolons are shown by thick lines in Fig. 1. Thus, what are commonly called first runners would all be in class A, second runners in class B, third runners in class C, and so on.

Secondary runners were those formed on secondary stolons which frequently arose from primary runners after the latter had been rooted for three or more weeks. They were given the letters of the runners from which they grew, with numbers showing their order of formation. Thus, the first secondary from a primary runner A would be A1, the second A2, and so on, while the secondaries from a B runner would be B1, B2, etc. Secondary stolons are shown by thin lines in Fig. 1.

Lateral runners were those formed on stolons which sometimes grow from blind nodes on other stolons. Such runners were classed as L1, L2, L3, etc., according to their distance from the blind node. Laterals grew most commonly from the earliest primary stolons, but also sometimes from secondary and other lateral stolons. Lateral runners have, in the past, commonly been supposed to make very undesirable plants, but their wide occurrence under cultural conditions, which can be deduced from Fig. 1, where the lateral stolons are shown

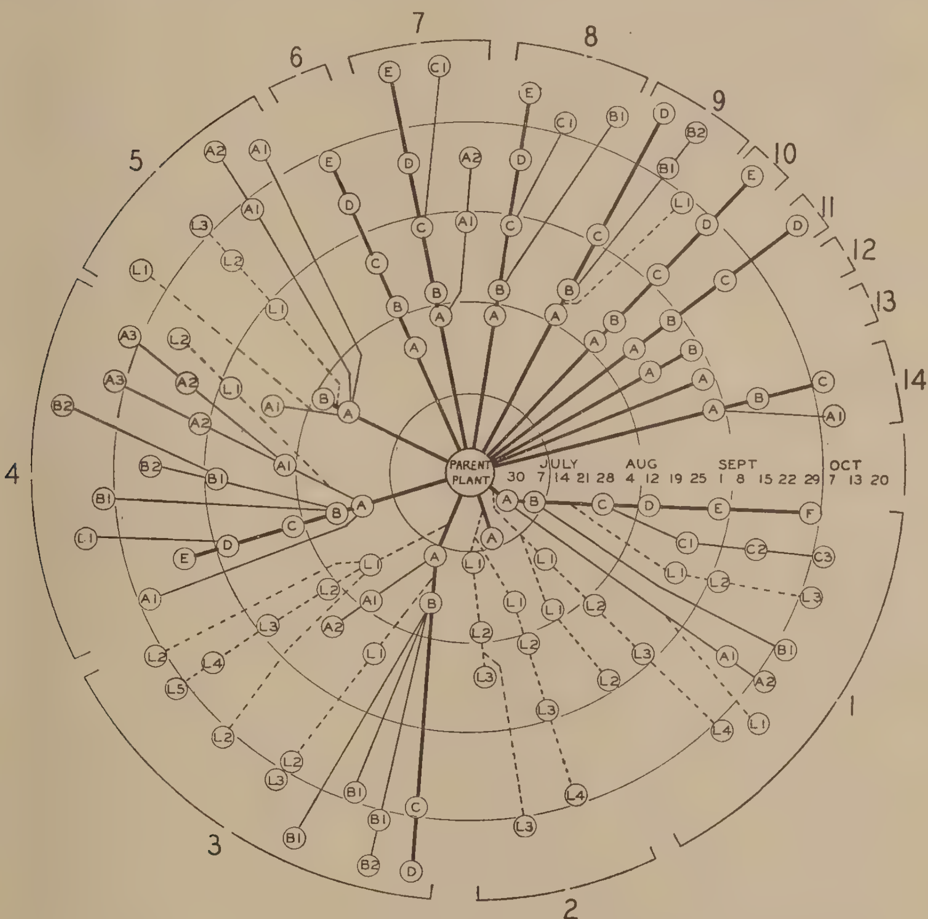

FIG. 1.

Diagram showing time of formation and relative positions on the stolons of a family of 122 runners formed by a Royal Sovereign Strawberry plant.

The outside numbers show the chronological order of the stolons. Thick lines show primary stolons, thin lines secondary stolons, and broken lines lateral stolons. Each small circle represents a runner, and the letters show the runner class. The large circles mark the five time periods tested. This diagram does not, of course, show the actual positions of the runners on the ground.

with broken lines, was probably not realized. Stolon 2 is composed almost entirely of laterals, but this is an exceptional case due to damage to the primary stolon, and the plants derived from its runners have not been included in the summaries, though they grew quite normally.

Specimens of runners of the various classes on an early formed stolon, and the relation of the classes to each other, are illustrated in Fig. 3.

Another method of classification tested was to group the runners according to "distance from the parent". This simply means that, counting along any stolon beginning at the parent, the first runner reached is in "Position 1", the second is in "Position 2", and so on. This groups the previous runner classes slightly differently. Thus in Fig. 3, runners marked A and L1 are in Position 1; those marked A1, B and L2 are in Position 2; those marked A2, B1, C and L3 are in Position 3, and so on. Runners in the same "Position" are not, of course, necessarily in the same time class.

It will be seen that a large amount of further sub-classification would be possible from the detailed stolon plans, but the results do not appear to call for this.

Results.

(1) *Distribution of runners of different classes.*

From Fig. 1 a good idea of the method and time of formation of the various classes of runner can be gained. The first runner to be formed must obviously be an A runner, the second is usually a B formed a week or a fortnight later. After this, secondaries and laterals may begin to form; meanwhile further primary stolons are pushed out from the parent plant. Thus, on July 7th, the only runners pegged from Plant D were a B runner on Stolon 1, and an A runner on Stolon 2; but on September 1st the runners pegged consisted of two A, two B, two C, one D, one E, one A1, one B1, two L1, one L2 and three L3 runners.

Table I gives a summary of the various classes of runner formed in different time periods, the figures given being the totals of the six plants in this trial. For the purpose of summarizing, the weekly time classes have been condensed to five, each covering a four-week interval. It will be noted that in the first two periods, primaries and first laterals are most numerous, while in the last two periods secondaries are relatively predominant; hence to a certain extent the figures for runner class and for time period are inter-related.

(2) *Time of formation and size of runner.*

The greatest difference between the runners at the time of lifting was in their size, which is well expressed by their weight. This depended very largely on their time of formation, as shown in Table II, which includes runners of all

TABLE I.

Distribution of Runners in Different Classes. Trial I.

		Time Period.					
		I Up to July 7th.	II July 8th-Aug. 4th.	III Aug. 5th-Sept. 1st.	IV Sept. 2nd-29th.	V Sept. 30th onwards.	Total.
	Class						
PRIMARY.	A ..	19	25	29	9	3	**85**
	B ..	8	21	22	14	6	**71**
	C ..	3	12	20	12	8	**55**
	D ..	—	4	12	15	8	**39**
	E ..	—	2	6	6	12	**26**
	F ..	—	—	3	2	2	**7**
	G ..	—	—	—	2	—	**2**
Total Primary		**30**	**64**	**92**	**60**	**39**	**285**
SECONDARY.	A1 ..	3	14	34	34	21	**106**
	A2 ..	—	6	18	32	31	**87**
	A3 ..	—	3	8	17	18	**46**
	A4-6	—	—	7	9	10	**26**
	B1 ..	—	3	20	19	12	**54**
	B2 ..	—	—	4	17	15	**36**
	B3-4	—	—	—	5	10	**15**
	C1-4	—	2	14	21	29	**66**
	D1-2	—	—	1	4	5	**10**
Total Secondary		**3**	**28**	**106**	**158**	**151**	**446**
LATERAL.	L1 ..	5	32	29	16	9	**91**
	L2 ..	2	12	36	25	14	**89**
	L3 ..	—	3	23	21	19	**66**
	L4-6	—	1	8	20	20	**49**
Total Lateral ..		**7**	**48**	**96**	**82**	**62**	**295**
GRAND TOTAL		**40**	**140**	**294**	**300**	**252**	**1,026**

TABLE II.

Relation between Time of Formation, Weight of Runner and Mortality in First Year. Trial I.

Period of Formation.	I Up to July 7th.	II July 8th-Aug. 4th.	III Aug. 5th-Sept. 1st.	IV Sept. 2nd-29th.	V Sept. 30th onwards.
No. of Plants	39	136	281	293	245
Mean weight, gm., at time of planting (November 1931) ..	30·5	16·7	7·2	4·4	1·75
Percentage Mortality in first year after transplanting (up to September 1932)	0	5·1	10·0	4·8	17·6

classes. The numbers of runners included in this Table are not identical with those in Table I; a few runners were excluded on account of abnormalities noted at time of weighing. Table II shows that the earlier the runner, the larger and heavier it had become by planting time in November. The difference is very marked, for the runners formed before August 4th averaged over ten times the weight of those formed after September 30th. The contrast between early and late formed runners, and the relation between weight and size of runner can also be seen in Fig. 3, which shows some consecutive series of runners formed on one stolon, and their fresh weights. On a given stolon the runners formed at different times naturally fall into various classes, but it is not so much the class as the time of formation which controls the runner size. This is shown in a later section in which the performance of runners of different classes, formed within the same time class, is discussed.

Under practical conditions the relation of weight of runner to subsequent plant performance need not be discussed separately from the time of formation, for the time classes automatically divide the runners into weight classes; but a further analysis to determine the effect of each of the two factors is given in Sections 7 and 8 below.

(3) *Mortality in the first year.*

The second item of importance shown in Table II is the mortality after transplanting. All the runners were dipped in 2% Lime-Sulphur solution (to check Tarsonemid mite*) and were planted out (with a trowel) immediately after weighing, in good weather, in November. Although a total of twenty-five ground frosts were recorded in November and December, the soil temperature at 4 in. depth for these months showed a mean value of 43·5° F., and most of the plants became well established. The greatest mortality was with the smallest runners. The plants of time period I, with a mean weight of 30·5 gm., suffered no losses at all, but 17·6% of the plants of time period V, with a mean weight of 1·75 gm., died in the first year—the great majority of them before the winter was over. This is not surprising, for reference to Fig. 3 shows that runners of this weight were much smaller than would normally be planted commercially, and in some cases their root systems were very small. It is interesting to note that only 4·8% of the runners in period IV, with a mean weight of 4·4 gm., died, compared with 10% of the plants with a mean weight of 7·2 gm. in period III. The reason for this is not clear, but it may have some connection with the age of root of the runner.

The total mortality in Trial I was 9·4% of the runners planted. A separate analysis of the runners according to their weights at the time of planting, shows

* This was the best control method known at the time. The warm water treatment was used in later trials.

that the mortality was 13·7% in those weighing 0·5 to 4 gm., 6% in those weighing 5 to 8 gm., and only 4·6% in those weighing over 8 gm.

The general conclusion is that, under favourable conditions, any well rooted runner stands a good chance of becoming established, but that the very smallest runners are the first to suffer under adverse conditions.*

Statistical treatment of records.

It was found that even within the classes chosen, there was still considerable plant-to-plant variation, so in all cases the means of as large a number as possible of comparable plants are given. With the large numbers used, it was not practicable to calculate separate standard errors for each mean of each record, but in cases where the significance of a difference between means was doubtful, an analysis of variance was carried out on the figures for 120 runners, i.e. ten selected at random from each class in periods II to V. A separate analysis was made to determine the significance of the difference between records of Time Class I, which had only sixteen runners, and the other time classes. In certain other cases, the Tables themselves give the figures for definite random samples, which have been given statistical treatment.

It is, of course, clear that none of the classes into which it has been possible to group the runners entirely eliminates plant-to-plant variation, but they have shown up some of the chief causes of variation in the early life of the plant.

(4) *Relation of time of formation to vigour and cropping.*

The records of paramount importance are those of vigour and cropping, and these are considered in Table III. Plants used as new runner parents and plants which died or were removed for disease or for any other reason before September 1934 are excluded from Table III, so the numbers are smaller than those in Tables I and II. The means for the various time periods are given in heavy type. The mean weight and therefore the size of runner at time of planting is shown in column 3 and follows out the time periods, as already discussed. The differences between runner weights of the various time classes are all statistically significant. The spread in the next spring (May), as shown by measurement of the diameter of each plant, is seen in column 4. As might be expected, the early formed runners were still the largest, and most of the differences are significant.

The plants were de-blossomed and their runners removed as formed, so that the whole vigour of the plant was concentrated on growth. By September, the spread of plant had become considerably levelled up. Although the plants from the earliest runners were still slightly larger, the differences between adjacent classes were not significant. The plants from runners of period V were still

* This point is particularly important where the warm water treatment is used, and this aspect will be discussed in a separate paper.

TABLE III.

Effect of time of formation and runner class on vigour and cropping of strawberries. Trial I.

	No. of Plants.	Weight (gm.) at Planting Nov. 1931.	Spread in inches.					Blossom Figure, 1932.	Fruit in gm.	
			May 1932.	Sept. 1932.	May 1933.	May 1934.	May 1935.		1933.	1934.
PERIOD I.										
Up to July 7th.										
Primary	9	30·4*	7·7	16·9	20·5	24·1	17·0	4·6	414	489
Secondary and Lateral ..	7	20·9	7·9	18·5	19·7	24·1	18·3	4·6	415	519
Total Period I. ..	**16**	**26·3***	**7·7**	**17·5**	**20·3**	**24·1**	**17·6**	**4·6**	**415**	**502**
PERIOD II.										
July 8th-Aug. 4th.										
Primary	28	20·3	6·9	16·5	18·5	22·3	14·5	3·7	389	446
Secondary ..	21	15·1	6·1	16·5	18·1	24·0	16·5	3·2	335	458
Lateral	29	13·3	6·3	18·1	19·7	24·0	16·9	3·6	384	467
Total Period II. ..	**78**	**16·3**	**6·5**	**17·1**	**18·9**	**23·4**	**15·9**	**3·5**	**373**	**457**
PERIOD III.										
Aug. 5th-Sept. 1st.										
Primary	49	9·7	5·9	16·9	18·7	23·6	16·8	2·4	385	479
Secondary ..	52	6·9	4·9	16·9	18·1	23·4	15·9	1·7	339	449
Lateral	58	6·3	4·7	16·7	18·9	24·0	17·1	2·0	390	471
Total Period III. ..	**159**	**7·5**	**5·1**	**16·9**	**18·5**	**23·7**	**16·6**	**2·0**	**371**	**466**
PERIOD IV.										
Sept. 2nd-29th.										
Primary	41	5·0	4·1	16·2	18·1	22·8	16·9	1·1	385	452
Secondary ..	112	4·6	4·1	16·5	18·9	23·9	17·2	1·1	382	485
Lateral	50	4·0	3·9	15·8	18·5	23·1	16·9	1·1	372	461
Total Period IV. ..	**203**	**4·5**	**4·1**	**16·4**	**18·7**	**23·5**	**17·1**	**1·1**	**378**	**473**
PERIOD V.										
Sept. 30th onwards.										
Primary	25	1·5	2·8	15·0	17·5	22·3	17·0	0·36	329	397
Secondary ..	106	1·9	2·6	15·4	18·3	23·0	16·6	0·55	356	456
Lateral	35	1·7	3·0	15·2	18·5	22·6	15·6	0·34	355	424
Total Period V. ..	**166**	**1·8**	**2·8**	**15·4**	**18·3**	**22·8**	**16·4**	**0·48**	**354**	**441**

significantly smaller than those of periods I to III. This is not surprising when it is remembered that a year previously the latter were ten times as heavy as the former, and at that time the period V runners were much too small to be suitable for commercial planting. The remarkable point is that the period V runners had so nearly caught up the rest in size. Subsequent records showed decreasing differences, which, with one exception, were not statistically significant. This exception, between periods I and V in May 1933, afterwards proved to be entirely due to a larger percentage of gaps in the former. The effect of gaps is dealt with later. It is seen, therefore, that under the conditions of the experiment, plants derived from runners differing widely in time of formation and size at planting, became practically levelled up in the first year, and in the second, third and fourth years showed no important difference in size. The size of plant increased up to the third year, but decreased in the fourth.

With regard to fruit, only a blossom figure is given for the first year, because the plants were de-blossomed. Under Kentish conditions, this is found to be the best practice, as the small loss of crop is more than repaid by the increase gained in the following year ; moreover, the expense of strawing and picking the small crop is saved.* The blossom figure gives some idea of the crop that might have matured, however. It is seen that the earlier and larger the runners, the higher was the blossom figure. These differences are statistically significant. This is quite to be expected, as the flower buds were laid down the previous autumn. An average, equivalent to at least one small truss per plant, was found even in the runners formed in September, but more than half of the runners formed in October failed to produce a blossom truss. It is quite clear that where it is desired to produce fruit in the first year it is most important to use the earliest formed and largest runners possible.

The first crop of fruit, produced in 1933, is shown in column 10. There was practically no difference between the yields per plant of periods II, III and IV. That of period I was about 10% higher, and that of period V about 5% lower than the rest. However, these differences are not statistically significant.

The crops in 1934 are shown in column 11. All were rather larger than, and the differences similar to, those of 1933. The increased crop coincides with the greater size of the plants, shown in column 7. The larger crop did not result in smaller fruits, for the mean weight per fruit was slightly larger in 1934 than in 1933. Again the differences are not significant.

There was a good show of blossom in 1935, but a disastrous frost on May 16th, when the grass temperature fell to 20° F., so severely reduced the crop that the records, though made, are not worth including here. No significant difference was apparent.

* The experimental evidence on which this conclusion is based will be given in a separate paper.

One factor that must be borne in mind is plant competition. The gaps left by plants which died, or were removed on account of disease, gave more room to the remaining plants. It was found that plants with gaps on one or both sides gave a slightly better performance than plants which had the full competition of their neighbours on both sides. While the proportion of deaths after planting was highest in the period V plants, the proportion of losses due to disease (as discussed in Section 9 below) was very much the highest in the period I (early July) plants. The total percentage of gaps due to both causes, after two years, was approximately: period I, 30% ; period II, 20% ; period III, 23% ; period IV, 11% ; period V, 21% ; consequently the surviving plants of period I had relatively more room than the others.

As the number of plants in period I was very small, it was thought desirable to include all healthy plants in the summaries, but if only those plants with no gaps beside them had been used, the period I figures would have been reduced relatively more than those of other periods. Therefore the levelling up of plant performance seen in Table III was even more pronounced than the figures indicate.

A fuller study of the effect of different distances of plant spacing is at present in progress at East Malling.

One of the most interesting points about the records is the remarkably good yield obtained from plants from all classes of runners. With plants spaced at 36 in. × 18 in., a crop of 400 gm. per plant would equal 8,535 lb. or 3·90 tons per acre ; and a crop of 500 gm. per plant, 10,668 lb. or 4·76 tons per acre.

The crop weights included the small fruits produced at the end of the season as well as the larger ones at the beginning. The average weight per fruit in 1933 began at 8·5 gm. at the first picking and gradually fell to 2·3 gm. per fruit at the last. Only the last picking, making up only 3·2% of the total crop, had an average weight of less than 3 gm. per fruit, which is about the minimum weight worth picking commercially. In 1934 the average weight per fruit began at 12·4 gm. and fell to 2·8 gm. Again, the last picking, which made up 6·4% of the total crop, was the only one with an average weight of less than 3 gm. per fruit. It can therefore safely be said that all the plants averaged over 3½ tons per acre of marketable fruit in 1933, and over 4 tons in 1934. The average yield of strawberries in England and Wales in 1936 was shown by the Ministry of Agriculture's quinquennial census (8) to be 0·74 tons per acre. Hence it is clear that great opportunity for improvement exists.

The 1935 figures, not given in detail here, show how the frost which killed all the early blossoms thereby removed the largest fruits. The mean weight per fruit at the first picking was 4·27 gm., and at the last 0·78 gm. Only about 40% of the crop weighed over 3 gm. per fruit. In effect, the 1935 crop was ruined.

Before going on to a detailed consideration of various types of runner, a word or two may be said about general runner performance already discussed, and illustrated in Fig. 4. This is a photograph of Trial I, and shows the general vigour and uniformity of the plants in their third year, May 1934. It should be remembered that this plot was composed entirely of the progeny of only six parent plants. Had the number of runners been limited to five per parent, only thirty plants could have been obtained ; yet it is seen that the 1,000-odd runners resulting from unlimited runner formation by these six healthy parents, have produced a plot as vigorous and as uniform as any grower could wish. The junior author is holding the measure, which is marked, for the purpose of the photograph, in feet.

(5) *Relation of runner class to vigour and cropping.*

Since the time of runner formation has so large an effect on performance in the early stages, and the proportion of runners of different classes varies in the different time periods, the effect of runner class alone is best considered within each time period. In Table III the three main classes, primary, secondary and lateral, are given for each time period. The primary runners were rather heavier than the others at the time of planting, except in the latest period. The size records in May 1932 showed that by this time the differences were lessening. By September 1932 none of them is significant. The differences in blossom figure in 1932 and in crop weights in 1933 and 1934 are also not significant.

A fuller analysis of the performance of the various runner classes is given in Table IV, in which the primary, secondary and lateral runners, formed in period III, are separated into their main components.

It is seen that the various classes of primary runner do not differ greatly among themselves. The class A runners are not superior to the others. In the secondary runners the B1 individuals are rather smaller than the others and they remained the poorest throughout, but little importance can be attached to this, as the B2 and C1-2 runners, not shown in the Table, were larger again. There is little difference between the various L runners. The differences again tend to disappear after the first year. In fact the L3 and L4 runners, about the smallest at planting time, had the largest crop in 1934. Examination of the records shows that the differences after September 1932 cannot be significant.

(6) *Effect of position of runner on stolon.*

The other method of classification suggested, that of position on the stolon reckoned as the distance from the parent measured along the stolon, is analysed in Table V. Since in the early periods the runners were mainly in the lower numbered positions and in the late periods in the higher numbered positions,

TABLE IV.

Effect of runner class on vigour and cropping of strawberries.

Trial I. Runners formed in period III (August 6th-September 1st, 1931).

	Runner Class.	No. of Plants.	Weight at Planting. gm.	Spread, inches. May 1932.	Spread, inches. Sept. 1932.	Spread, inches. May 1933.	Blossom Figure, May 1932.	Fruit, gm. 1933.	Fruit, gm. 1934.
Primary.	A.	11	8·3	5·5	16·4	18·7	1·9	370	460
	B.	13	10·2	6·7	16·4	18·1	2·2	380	490
	C.	11	10·4	5·3	17·5	19·5	2·5	405	470
	D.	8	11·0	6·7	18·7	18·9	3·1	455	485
Secondary.	A1.	17	8·5	4·9	17·3	18·1	1·9	350	495
	A2.	8	7·1	5·1	16·5	18·3	1·5	350	430
	B1.	13	4·4	3·7	15·4	17·3	1·2	335	400
Lateral.	L1.	16	6·0	4·5	16·0	18·5	1·5	375	450
	L2.	21	6·2	4·7	16·9	18·5	2·0	420	415
	L3.	15	6·9	5·3	17·1	19·3	2·4	380	550
	L4.	5	5·6	3·9	17·7	20·1	1·8	355	545

Values refer to means per plant.

the records of runners pegged in one early and one late period are given. To get a reasonable number of early plants, the records of runners pegged during two weeks had to be used. For the late period, all the runners were pegged in one week, viz. that ending September 29th, with the exception of four Position 1 runners, pegged on September 22nd.

TABLE V.

Effect of position on stolon, at two different times of formation, on vigour and on cropping. Trial I.

	No. of Plants.	Weight at Planting Nov. 1931. gm.	Spread, inches. May 1932.	Spread, inches. Sept. 1932.	Spread, inches. May 1933.	Blossom Figure, 1932.	Fruit, gm. 1933.	Fruit, gm. 1934.
Early (runners pegged July 14th-21st)								
Position 1	11	22·8	7·3	17·7	19·3	3·7	393	512
2	11	17·7	6·5	18·5	20·3	4·0	434	444
3	5	21·0	7·9	17·7	19·7	5·2	388	594
4	2	15·5	8·9	19·7	22·7	5·5	375	325
Late (runners pegged Sept. 22nd-29th)								
Position 1	6	4·2	3·3	13·2	16·2	1·0	290	444
2	14	3·6	3·3	15·8	18·9	0·6	365	434
3	14	3·8	3·9	16·4	18·7	0·9	368	456
4	18	4·1	4·5	17·3	19·1	0·8	394	484
5	12	3·3	3·3	15·4	18·3	0·8	346	461

Examination of Table V shows that, within each period, there is very little difference between the runners in the different positions, and that such differences as there are do not run according to position.

The effect of time of formation on early vigour can be seen very clearly, and bears out the results already given in Table III. There is no difference between the Position effect in the different time periods.

It is clear that neither runner class nor position on the stolon, apart from their correlation with time of formation, are factors of great importance in the performance of healthy plants. Points connected with virus disease incidence are discussed in section 9.

(7) *Size of runner and plant performance.*

Study of Tables III, IV and V suggests that, in general, the runners that were largest to begin with tended to give the best results for a period afterwards. The main factor in size of runner is time of formation, but there is variation in size of plants even from runners pegged down in the same week.

To investigate the effect of size of runner apart from time of formation, the results from samples of large and small runners, all pegged down on the same dates, were chosen. As only fifteen of each size could be found that were pegged in one and the same week (September 1st), a further ten of each size, formed the previous week (August 25th) were added. The large runners had a mean weight of 10·1 gm. and the small ones 3·4 gm. in each of the two weeks, so a very satisfactory sample of twenty-five comparable large and small runners was obtained. The results are shown in Table VI. There was a large and

TABLE VI.

Effect of size of runner, apart from time of formation. Trial I.

	Weight at Planting Nov. 1931. gm.	Spread, inches.					Blossom Figure, 1932.	Fruit Weight, gm.	
		May 1932.	Sept. 1932.	May 1933.	May 1934.	May 1935.		1933.	1934.
Large	10·1	6·2	17·7	18·6	23·5	16·4	2·64	381	492
Small	3·40	4·1	15·4	18·4	23·6	17·1	0·88	337	473
Significant Difference	1·14	1·4	1·5	1·7	—	—	0·48	73	110

significant difference in spread in the spring following planting. By September in the same year the difference had decreased, but was still just significant. By the following May the difference had almost disappeared, and was not significant. The largest difference of all was in blossom figure in 1932, and this was highly significant. It is noteworthy that this last figure is roughly proportional to the weight at planting, as shown both in this Table and in Table III. In the second

season, 1933, although the plants from runners that were heaviest at planting had most fruit, the differences in this connection are not significant. In 1934 the plants were almost exactly equal in size, and the crops were also very nearly equal.

(8) *Time of formation and plant performance.*

The natural corollary to the above analysis is one showing the effect on performance of time of formation, apart from size of runner.

For this purpose, samples of runners of equal weights were chosen from two periods of formation. It was obviously impracticable to choose very widely differing periods, since there were so few small runners in the earliest time periods and so few large ones in the latest; but it was found possible to use the results of samples of twenty-five runners weighing 5 gm. each from the early period, August 19th to September 1st, and the late one, September 22nd to 29th.

The performance of the plants from these runners is shown in Table VII. It is seen that there is practically no difference in size or in crop between the

TABLE VII.

Effect of time of formation of runner, apart from size, on performance. Trial I.

	Weight at Planting Nov. 1931. gm.	Spread, inches.			Blossom Figure, 1932.	Crop, gm. 1933.
		May 1932.	Sept. 1932.	May 1933.		
Early (Aug. 19th-Sept. 1st)	5·0	4·1	16·6	19·0	1·24	371
Late (Sept. 22nd-29th)	5·0	4·7	16·9	19·5	1·12	391

two samples. The late plants performed slightly better than the early ones, but none of the differences is significant. It is interesting to note that although the plants from the early runners were a little smaller in diameter than those from the late ones, they had a slightly higher blossom figure in 1932, which is the main difference that might be expected. Even this is small.

Taking Tables VI and VII together, it is clear that the effect of size of runner at the time of planting on subsequent plant performance is much greater than the effect of the time of formation. For practical purposes these two factors are interdependent, however, as already stated.

(9) *Runner class in relation to incidence of virus disease.*

One of the reasons for the excellent performance of the plants of these selected clones was undoubtedly the fact that it was possible to identify and

remove plants that became affected with the Yellow-edge disease, and so reduce the risk of attack on the remaining plants. The serious nature of this disease in this country was recognized by Harris in 1931 (4), and it is through his most helpful collaboration that records on the incidence and effect of the disease were obtained.

Harris (5) has already quoted figures from the present Trial I showing that Yellow-edge rapidly causes great reduction of vigour and cropping. It is sufficient here to refer to Fig. 5, which shows two sister plants produced on the same stolon in the same week and planted side by side in November 1931. Both appeared healthy in May 1932, but by September 1932 Y was recorded as "suspicious Yellow-edge". By May 23rd, 1933, when the photograph was taken, very severe symptoms had developed. The plants were allowed to crop and H produced 390 gm. of fruit, of a mean weight of 5·1 gm. per fruit, while Y produced 205 gm., of a mean weight of 3·7 gm. Plant Y was removed on June 28th, but H and three adjacent plants developed Yellow-edge symptoms by October. This example of rapid deterioration and spread along the row from diseased to healthy plants, is typical of many cases recorded on this plot, although diseased plants were removed as soon as possible after recognition. Had the diseased plants not been removed, the whole plot would certainly have become infected much more rapidly. The fact that this disease can be carried from diseased to healthy plants by the Strawberry Aphis (*Capitophorus fragariae* Theob.), as shown by Massee (6), emphasizes the seriousness of the problem, for it is very difficult to control this aphis under field conditions. It may be noted in passing that plant H was the fifty-sixth runner formed by its parent, but it certainly shows no lack of vigour.

In view of the importance of the disease it is of interest to note that, under the conditions of this trial, there appeared to be some correlation between period of formation, runner class and incidence of Yellow-edge in the first year. This is shown in Table VIII.

It is seen in Table VIII that 30% of the earliest formed runners showed Yellow-edge symptoms in the year following planting. Later formed runners showed smaller percentages, down to 4% for period V. Similarly, 22·1% of the A class runners showed the disease in the first year, while B runners showed 16·9%, L1 runners 18·2%, and other runners, 7·2%. Thus, the earliest runners, and those nearest the parent plant in length of stolon, had the largest percentage of Yellow-edge. Though the numbers are not very large, the trend is very clear.

Two explanations seem worth consideration: (1) that the larger plants resulting from early runners proved more attractive or gave better shelter to virus-bearing aphides during 1932, and (2) that a late infection of part of the clonal runner beds occurred shortly before the runners were lifted in 1931,

TABLE VIII.

Incidence of Yellow-edge disease in first season (November 1931 to September 1932). Trial I.

Time Period	I.			II.			III.			IV.			V.			Total of All Periods.		
	Total Plants.	No. Y.	% Y.	Total Plants.	No. Y.	% Y.	Total Plants.	No. Y.	% Y.	Total Plants.	No. Y.	% Y.	Total Plants.	No. Y.	% Y.	Total Plants.	No. Y.	% Y.
A	14	4	**28·6**	20	6	**30·0**	23	5	**21·7**	9	0	**0**	2	0	**0**	68	15	**22·1**
B	5	4	**80·0**	19	3	**15·8**	17	2	**11·8**	13	1	**7·7**	5	0	**0**	59	10	**16·9**
L1	5	1	**20·0**	29	4	**13·8**	24	6	**25·0**	15	2	**13·3**	4	1	**25·0**	77	14	**18·2**
A1	3	0	**0**	13	1	**7·7**	29	4	**13·8**	33	2	**6·1**	19	0	**0**	97	7	**7·2**
All other classes	3	0	**0**	43	5	**11·6**	160	18	**11·3**	209	12	**5·7**	172	7	**4·1**	587	42	**7·2**
Total of All Classes	30	9	**30·0**	124	19	**15·3**	253	35	**13·8**	279	17	**6·1**	202	8	**4·0**	888	88	**9·9**

No. Y and % Y. = Number and percentage of plants showing definite Yellow-edge virus symptoms between time of planting, November 1931, and September 1932.

and had spread only to limited lines of runners, either by the aphides themselves or through the stolons, by lifting time. A third explanation, viz. that the virus may have been equally present, but in a masked condition, in the initially smaller plants, is not supported by the later records.

The first explanation would fit the figures in Table VIII. Further, the mean weight at planting of all the runners that developed disease symptoms in the first season was 11·7 gm., as compared with the general mean weight of 6·6 gm. for all runners. Hence it is quite clear that the large runners suffered most.

The second explanation is only partly supported by the records. No disease symptoms were noted on any of the six parent plants in 1931, and only two of them developed virus symptoms in 1932. Of the runners produced by these two late infected plants in 1931, 10·3% developed virus disease symptoms in 1932; but 9·7% of the runners produced by the other four plants also developed virus symptoms in 1932. Hence the virus disease in the runners could not have come solely from the parents, otherwise all the parents themselves would have shown symptoms in due course, unless complete masking occurred, and this is unlikely in Royal Sovereign. Nevertheless, some support can be found for the idea of infection from the parent, for 25% of the virus diseased runners from those parents which themselves later showed infection, were in Position 1 on the stolon, i.e. next to the parent plant, while only 15·7% of the diseased runners from the non-infected plants were in Position 1. Further evidence can be given to show that the disease spreads from one runner to the next on the stolon in the runner bed. In thirty out of the ninety-one diseased individuals recorded (including the new runner parents) the runner that developed disease symptoms was, in the runner bed, immediately next on the stolon to another runner that also developed virus disease symptoms. Only eight of these thirty individuals were next to each other or to another diseased plant when planted out, which would favour plant-to-plant spread in 1932. Therefore twenty-two are left in which the disease apparently spread before the runners were lifted from the runner bed. Thus it appears that the runners were lifted and separated just at the crucial stage when the viruliferous aphides, or the disease itself, not yet showing symptoms, had begun to spread from parent to runner, or from runner to runner.

The distribution of the diseased plants was very even over the whole plot; there was no question of a localized new infection. It is, of course, likely that besides the initial infections, further sporadic infestation by viruliferous aphides during 1932 also occurred, to which many of the sixty-one other cases were probably due. The first explanation, that in this trial the aphides apparently preferred or became established best on the earlier-formed plants, if correct, is a remarkable fact. It is possible that the young leaves of the larger plants are

more sheltered, softer, more succulent and attractive to aphides than those of the small plants, which are more open in growth. This question needs further investigation.

The greater incidence of attack on the large and early runners was certainly a point of great importance in this trial, for the period I runners, naturally few in the first place, were so much reduced by disease in the first and second years after planting, that only sixteen out of the thirty plants survived to crop for two years. If further research shows that such infection is common, this danger may be a serious drawback to the use of the largest runners if stringent virus disease and aphis control measures are not possible.

A general discussion of all the factors dealt with in Trials I and II will be given after the latter has been described.

TRIAL II.

In order to check the results obtained in Trial I, and to get a fuller statistical analysis of the effect of time of formation of runner, which appeared to be the main source of runner difference in Trial I, a second trial was planted in March 1933. It was arranged in definite plots, for statistical comparison of the performance of runners produced in five main fortnightly periods. Individual plant records were taken as before, so that the history of each plant could be followed and grouping of the records of any desired set of plants arranged as in Trial I. Also, within each time class, the experiment could be treated as a uniformity trial to obtain information as to the most desirable size and shape of plot. This aspect will be dealt with in Paper II of this series.

It should be noted that Trial II was spring planted, and Trial I was autumn planted. Hence both periods of normal commercial planting were tested.

Methods and Material.

The twenty-four parent Royal Sovereign plants set aside for runner production were all of one clone, chosen for its very satisfactory vigour. Hence the runners used in this trial all belonged to a single clonal race.

The runners were pegged and mapped at weekly intervals, as before. Five parents and their families were discarded because Yellow-edge appeared in them, and one small parent failed to become established. The remaining eighteen parents produced 2,754 runners, an average of 153 each. These were lifted, washed and weighed between February 21st and March 1st, 1933, and were divided into seven time-classes as follows:—

(a) Runners pegged down before July 15th, 1932.
I. ,, ,, ,, July 15th to 29th.
II. ,, ,, ,, July 30th to August 11th.
III. ,, ,, ,, August 12th to 25th.
IV. ,, ,, ,, August 26th to September 8th.
V. ,, ,, ,, September 9th to 22nd.
(b) ,, ,, ,, after September 22nd.

Only runners of periods I to V were used, the few formed in the extreme periods (a) and (b) being discarded. This was necessary since large and equal numbers of plants were required for each treatment in the planning of the trial plots. These periods are practically equivalent to closer subdivisions of the time periods II to IV in Trial I. Moreover, they cover the range of commercial importance, since the proportion of runners formed before mid-July is generally negligible in practice, and those formed after mid-September are generally too small for commercial use.

The runners were given the warm water treatment before planting (immersion for twenty minutes in water at a constant temperature of 110° F.) to ensure that they started free from Tarsonemid mite, and were planted on ground adjacent to Trial I on March 2nd (ten plots) and 7th (fifteen plots), 1933. The weather at that time was so wet that planting was interrupted for four days. Sunny weather soon came on, however, and the soil at 4 in. depth warmed up from a mean temperature of 41·1° F. in March to 47·5° in April. As is usual after warm water treatment, growth was checked for a few weeks, and it was feared that dry weather might cause heavy losses. However, the runners soon revived, in the remarkable way often seen after this treatment, and developed into a really magnificent lot of plants.* The percentage mortality in the first year was only 4·5%.

ARRANGEMENT OF PLOTS.

The plots were arranged in a 5×5 Latin square with five replications of each time class. Each of the twenty-five plots consisted of 48 runners, making a total of 240 of each time class. Each plot was arranged in four rows of 12 runners, with an extra one as a guard at each end of each row, so bringing the actual number of runners in each plot up to 56. There was also a guard row along each outside edge of the trial. The records made on the guard plants were disregarded in summarizing and analysing the records. The number of individual plants of which records were made was therefore 1,200, plus 220 guard plants.

* The remaining clonal runners not used in Trial II were planted up in a special nursery bed for runner production, and formed the nucleus of the East Malling Strain B clone, of which over 1,000,000 plants were distributed in 1936-7. This was the first of the Research Station's "isolated block" runner beds.

RECORDING.

At the end of April 1933 the plants were de-blossomed according to recommended commercial practice. In order to obtain a preliminary indication of crop potentialities, the trusses were divided into three grades to secure the blossom figures, as in Trial I. At the end of May, records of the spread of the plants were made.

As a certain amount of aphis infestation had occurred in Trial I, a very thorough spray programme was undertaken to prevent its spread. Nicotine and soft soap sprays were applied to the plots in both Trials at approximately fortnightly intervals from May 25th to the end of July 1933. This treatment, though not economical on a commercial scale, apparently had the desired result, for there was practically no Yellow-edge attack in Trial II during that season. Health surveys were made, noting all abnormal plants, and by the end of October definite Yellow-edge symptoms were observed in only five plants, and these were removed.

Measurements of height and spread of plant were taken in October 1933, and again after growth had started in May 1934. The total number of blossom trusses on each plant was counted, without attempting to grade them into sizes, as it would have been impossible to do this without damaging the plants. At that time the plants looked extremely healthy and vigorous, and they produced excellent crops. The crop for each plant was weighed separately. In the spring of 1935 further records of height and spread were taken. Alas, the prospect of a good crop was spoilt by the severe frost in May, which killed a large percentage of the blossoms, but it was decided that some record of the damage should be made. Four plants per plot were therefore chosen at random, one in each row, and the numbers of damaged and undamaged blossoms in each truss were recorded. From these figures the percentage of frost damaged blossoms was calculated. This was about 41%, and the damage was spread evenly over the plots, affecting no class of runner more or less than another. This estimate was probably lower than the actual percentage damage to the potential crop, as more damage was done to the trusses which had opened earliest, and these were more vigorous than those which opened later.

The crop, though small compared with that in 1934, was recorded in the same way as in that year. A further record of spread was made in September 1935.

During the summer of 1935 there was a severe infestation of aphis* ; Yellow-edge disease spread rapidly in both Trials I and II, and, by November, 75% of the plants were certainly affected with the disease. It was therefore

* In this year the plants were sprayed with nicotine only twice, as it was considered that the information then available on the life history of the aphis did not justify the elaborate spraying programme previously carried through.

considered useless to make further records, for a sufficient number had already been collected to compare with those derived from Trial I, and to serve as a basis for deciding on the best size and shape of plot for various experimental purposes.

RESULTS.

(10) *Time of origin of runner.*

The effect of time of origin of runner on its subsequent performance is seen in Table IX. In this the plot of forty-eight plants is taken as a unit, and the statistical differences are calculated on the plot totals. This is the most satisfactory procedure under the conditions that prevailed, as the few missing plants were very evenly distributed over the plots (on the average, two per plot). In this Table, too, the process of gradual levelling up of the plants formed in the different periods can be seen.

In weight at planting there is a significant difference between all five time periods, although, as already mentioned, the periods are shorter than in Trial I. The mean weights ranged from 18·9 gm. in period I to 7·2 gm. in period V. These figures are rather higher than those for the corresponding runners in Trial I. The increase is probably mainly due to the runners having remained four months longer in the runner bed ; for, although growth is very slow in December and January, the runners grow actively in November and again in February.

The records of spread in May 1933, however, show that although after only two months' growth from the time of planting out some levelling up had already taken place, yet the period I plants were still significantly larger than those of period V.

There are, however, much clearer differences in the blossom figure for May 1933, which show that the plants from the originally largest runners had the greatest cropping potentiality in the year of planting.

The records of the heights and spreads of the plants in October 1933 show very little difference between the classes. Thus, in six months in the field, the plants had, for all practical purposes, levelled up completely. From Fig. 6, which shows plots of periods I to V, it is evident that the originally smaller plants have caught up the others, since all the plots appear so uniform. There were, however, very slight differences in favour of the plants from the early-formed runners in number of blossom trusses in May 1934, those between period I and periods III and IV being just significant. This was not reflected in the crop weights, however, for with them no differences were significant.

In the autumn of 1934, the period I plot nearest to Trial I, became severely infected with Yellow-edge disease, and several plants had to be removed. In

TABLE IX.

Effect of time of formation of runner on vigour and cropping of strawberries.
Trial II.

Time Period.	Weight at Planting, March 1933. gm.	May 1933. Spread. in.	Oct. 1933.		May 1934.		May 1935.		Sept. 1935. Spread. in.	May 1933. Blossom Figure.	May 1934. No. of Blossom Trusses.	1934. Fruit. gm.	1935. Fruit. gm.
			Spread. in.	Height. in.	Spread. in.	Height. in.	Spread. in.	Height. in.					
I. July 15th-29th ..	18·9	8·29	14·9	5·77	19·4	10·2	15·9*	6·5*	18·2	3·92	13·7	482	136*
II. July 30th-Aug. 11th	13·6	7·89	14·9	5·60	19·4	10·2	17·0	6·7	16·7	3·40	12·8	466	142
III. Aug. 12th-25th ..	12·0	7·85	14·9	5·60	19·5	10·3	17·1	6·8	19·3	3·04	12·4	449	142
IV. Aug. 26th-Sept. 8th	8·8	7·75	14·3	5·41	19·6	10·3	16·6	6·6	18·5	2·27	12·5	459	145
V. Sept. 9th-22nd ..	7·2	7·21	14·5	5·67	19·5	10·3	16·9	6·7	19·6	2·10	13·0	483	149
General Mean (all periods)	12·1	7·79	14·7	5·60	19·5	10·3	16·7	6·7	18·4	2·94	12·9	468	143
Standard Error ..	*0·34*	*0·24*	*0·32*	*·099*	*0·35*	*0·17*	—	—	—	*0·16*	*0·38*	*11·4*	—
Significant Difference ..	1·05	0·74	1·00	0·31	1·09	0·53	—	—	—	0·51	1·17	35·0	—

* Mean of 4 plots.

summarizing subsequent records this plot was omitted, as the number of missing plants was so much greater than that for any other plot.

The records for height, spread and fruit crop in 1935 demonstrate further the insignificant differences between the different periods.

(11) *Effect of runner class.*

Records of lots of twenty plants each, representing various runner classes and selected at random from time period III, are assembled in Table X. They

TABLE X.

Effect of runner class on vigour and cropping of strawberries. Trial II.

Runner Class.	Weight at Planting. gm.	Spread in inches.					Blossom Figure, May 1933.	Fruit.	
		May 1933.	Oct. 1933.	May 1934.	May 1935.	Sept. 1935.		1934 Weight. gm.	1935 Weight. gm.
A.	13·6	8·3	16·7	21·3	19·3	21·3	2·85	471	144
B.	12·7	7·6	15·1	20·7	17·6	20·8	3·20	468	148
C.	14·0	8·5	15·7	20·1	17·7	20·5	3·40	513	151
A1.	12·9	9·5	16·4	21·1	18·3	20·3	3·85	489	165
L1.	10·5	8·5	14·1	19·8	18·9	20·4	2·95	441	170

Figures represent means per plant of plants taken at random from time period III, August 12th-25th.

show results very similar to those found in Trial I (Table IV). The L1 plants were slightly weaker at first, but soon caught up the others. The largest and the smallest runners at planting time gave the heaviest and lightest crops respectively in 1934, but none of the differences can be significant. The 1935 crop figures—for what they are worth, after the frost damage—were the reverse of these results. It is clear that runner class, apart from time of formation, has no important effect on plant performance.

Thus, Trial II confirms and emphasizes the results of Trial I, namely that, under the conditions that prevailed, the plants from the different classes of runners became practically uniform in the year following planting.

(12) *Incidence of virus disease.*

Only five cases of Yellow-edge were found in Trial II in the first season, probably as a result of the careful roguing applied to the parents, and probably also of the intensive spray programme adopted. Three of these cases were in period I plants and two in period V plants, so that no evidence can be added from this trial to that obtained in Trial I to warrant further discussion of disease incidence here.

DISCUSSION AND CONCLUSIONS.

This investigation has shown conclusively that all runners from a healthy parent have the potentiality to develop into vigorous and fruitful plants after transplanting, provided they become properly established. Lateral and secondary runners are no worse and no better than comparable primary runners.

Runners that are large, from whatever cause, have a certain advantage at first over small ones. In the present trials this advantage became insignificant during the first season, except in one extreme instance in which the plants from the very largest runners remained significantly bigger than those from the very smallest until the second season.

None of this information is very surprising, for every individual of a vegetatively reproduced race of plants is normally identical in make up with the parent. The essential matter is that each new individual, when severed from its parent, should possess sufficient reserves to enable it to establish itself in its new environment. Once the new plant is established, the environment becomes the factor controlling its behaviour and destiny. There must, of course, be a limit at which the root system (inevitably injured during lifting) and the reserves of a very small runner are not sufficient to enable it to withstand the forces of drying and other adverse factors following on planting out in the field. Under such conditions the plant is checked and, even if it survives, may lag behind its more fortunate neighbours. The results presented in this paper show, however, that this critical limit is below the size of runner normally used for commercial planting.

On the other hand, what may perhaps be called super-runners, weighing about 25 to 40 gm. each, which can be obtained in small numbers by selection of the earliest-formed runners, and particularly by the limitation of runner development to three or five per parent, may, under certain circumstances, make a better start after transplanting than smaller runners and maintain their lead beyond the single season revealed by the present Trials. This was probably the case in Ball's work (3) already mentioned. Such runners usually have several crowns and very large root systems and, although they are much more difficult to transplant properly, they certainly possess larger reserves than smaller ones.

The question of planting only super-runners does not arise, however, under practical conditions, for such runners, while possibly of interest to the home gardener, are too few and too costly to be of service to the commercial grower. The abandonment of the system of awarding a Super Certificate for runners limited to five per parent, under the Ministry of Agriculture's Certification Scheme (7), is testimony to the impracticability of such runner production under commercial conditions. The investigations described in the present paper show

further that, provided healthy material is used at the start, such a measure is quite unnecessary. *Excellent results can be obtained from any runner that is large enough to become established, provided it is and remains healthy.*

The authors do not consider that the results would have been very different if the plants had not been de-blossomed in the first season. In another trial (1) maiden plants that had become large by May (i.e. early-planted) showed slightly greater benefit from de-blossoming than smaller ones (i.e. late-planted). Hence it is likely that the levelling up of the plants from large and small runners in the present trials would have been still more rapid if the plants had not been de-blossomed.

The importance of planting healthy material cannot be over-emphasized. Virus-infected runners are seriously handicapped from the start, and provide a source of infection for their healthy neighbours. The incidence of the Yellow-edge disease was undoubtedly the limiting factor in the commercial life of the plants in these Trials, and the control of this disease is thus a factor of supreme importance. This problem is now receiving attention at East Malling in investigations in which mycologists, entomologists and pomologists are collaborating.

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SUMMARY.

1. Individual plant records of about 2,500 Royal Sovereign strawberry plants of selected clonal races were made, starting from the time of their formation as runners on the parent plant and continuing to the end of their commercial life.

2. Great variation in weight of runner at time of planting was found, viz. from about 40 gm. for the earliest-formed to less than 1 gm. for the latest-formed runners.

3. All healthy runners, whether large or small, early or late, and of whatever position on the stolon, were found to possess the potentiality of becoming equally vigorous and fruitful plants, once they had become established. In the first season after planting out, the plants from the largest runners were the most vigorous and had the greatest cropping potentiality, as shown by blossom records ; but those from the smaller runners caught them up by the second season.

In the second and later seasons there were no important differences in vigour and cropping, between plants from runners of different sizes at planting, time of formation, or position on the stolon.

4. There is no need to limit the number of runners per parent in order to get satisfactory results.

5. The smallest runners showed the highest mortality following planting. Under favourable conditions very small runners can be successfully established, but for commercial purposes runners weighing less than 3 or 4 gm. (i.e. about eight washed runners to the ounce) are not recommended.

6. The factor limiting the commercial life of the plants was the incidence of the Yellow-edge disease. The plants did well so long as they remained healthy, but rapidly deteriorated when they became infected.

7. The earlier-formed and larger runners showed a higher proportion of Yellow-edge infection than the others. Possible causes and implications are discussed.

8. The most important basis of runner selection, under the conditions of the Trials, was freedom from virus disease.

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(*Received* 2/2/38.)

FIG. 2.

A typical clonal family of 306 runners produced by a two-year-old Royal Sovereign strawberry plant. The families of one-year-old plants were similar but not so numerous.

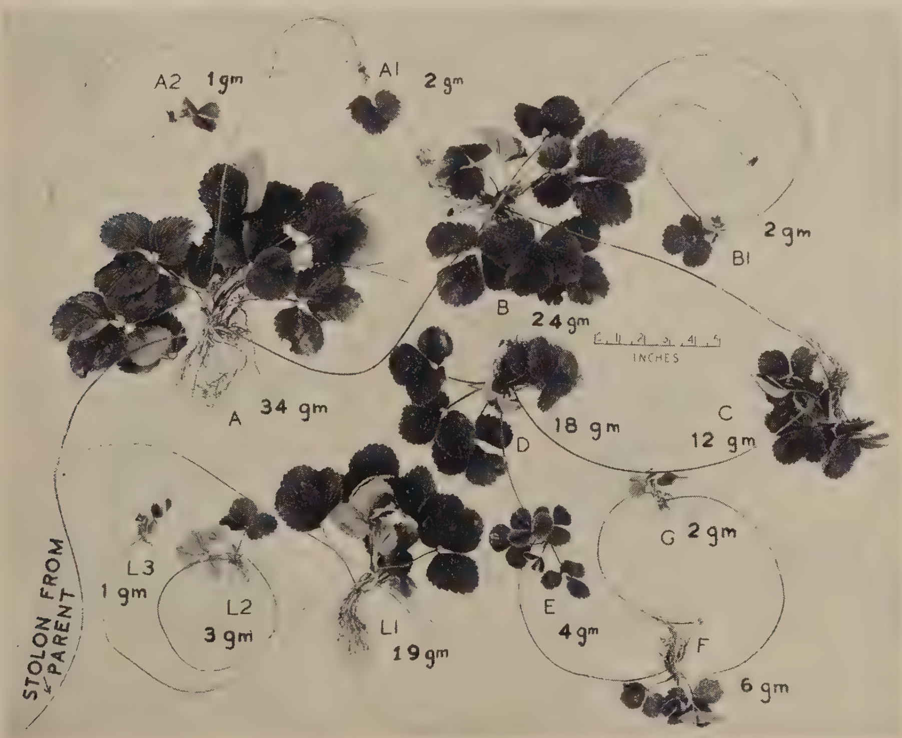

FIG. 3.

Consecutive series of runners formed on one stolon, showing (1) Division into classes (marked with different letters) according to position on stolon, and (2) Relation between size of runner and fresh weight.

Fig. 4.

Trial I on May 30th, 1934, showing vigour and uniformity of plants in the third year. Some of the individual clonal parents used for Trial II are seen on the right.

Fig. 5.

Two Royal Sovereign strawberry plants. Y = severely affected with Yellow-edge disease, H = healthy.

Both were produced on the same stolon on August 19th, 1931. Both appeared healthy in May 1932; Y showed Yellow-edge symptoms in September 1932. Photograph taken May 23rd, 1933. Y was removed June 28th, 1933, but H and three adjacent plants developed Yellow-edge symptoms by October 1933.

Fig. 6.

Trial II on May 30th, 1934, showing uniform vigour and size of plants in the second year. The outside row (guard row) on the left is of Period V plants. The next four rows contain (front to rear) plants of Periods I, IV, III, V, II, and the next four rows, those of Periods IV, V, I, II, III. It will be noted that no distinction in vigour can be seen between the different plots.

STRAWBERRY CULTIVATION STUDIES. II.

VARIABILITY IN INDIVIDUAL PLANT SIZE AND CROPPING, WITH SPECIAL REFERENCE TO AREA AND SHAPE OF PLOTS FOR FIELD EXPERIMENTS

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In the first paper of this series (4), the building up of a vigorous and healthy clonal race of Royal Sovereign strawberry plants was described. In this process a number of possible causes of variability were investigated and their effects shown, disease being evidently the most important. This study was a necessary preliminary towards greater accuracy in more advanced stages of experimental work on the strawberry, apart from its value in providing a nucleus of healthy plants for the industry. The next step was to use the information obtained to establish the most economical size and shape of plot for future use.

During the ten-year period of work on strawberries, two uniformity trials have been carried out, the first on the type of material used in 1927, collected during a study of different commercial strains of Royal Sovereign, and the second on the clonal material raised from a single plant of one of these strains.

The first of these trials, which may be termed a normal uniformity trial, consisted of a study of plot to plot variation, where the smallest unit was a plot of 92 plants, taken at random from the progeny of a single commercial strain which had been rogued for disease for one year at East Malling. The second involved not only recording the performance of individual plants, but also seeking to estimate and eliminate the effect of factors inducing plant to plant variation, which might arise in the runner bed.

The First Trial.

The first field experiments at East Malling with Royal Sovereign strawberries were begun in 1927. At that time little was known about the variability in strawberry material, and the experiments were planned with large plots of from 92 to 684 plants. They were carried out to test the effect of strain, time and method of planting, and of deblossoming in the first season, and have been described elsewhere (1, 2). The three strains used were collected from commercial sources and all showed such great variability that, with four or six replications of plots of 92 plants, it was possible to prove only a 20-25% difference between the treatments.

The plots then used were thus on the generous side, but to get a nearer estimate of an economical plot size and the required number of replications, the first uniformity trial was planted in October 1928, using runners taken from plants of a single strain, which had shown the best performance in the previous season's trial. There were 72 plots of 92 plants each, then considered the minimum economic size, arranged in four rows of 23 plants, and all received uniform treatment.

The crop weights per plot were recorded for the four years 1929-32.

For purposes of statistical analysis, the main plot was split up in various ways into randomized blocks and Latin squares, as shown in Diagram I. Each year's crop was then analysed, treating the trial in the different ways and using Fisher's Analysis of Variance (3).

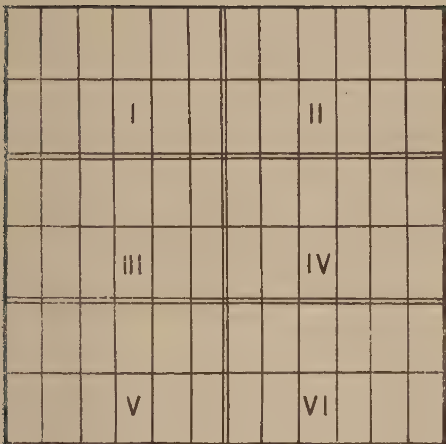
Only two sizes of plot were compared, the original one of 92 plants and one of double the size formed by combining adjacent plots. Approximately square plots were compared with longer narrow ones, and the relative accuracy of Latin square and randomized block designs determined.

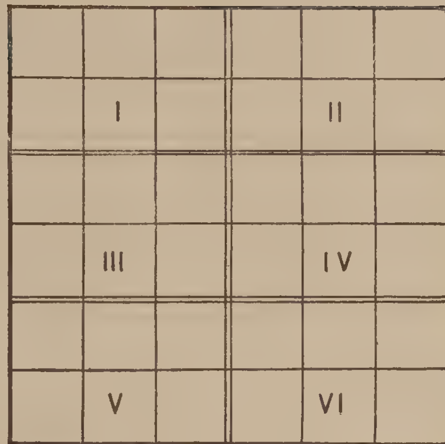
The comparative accuracy of each new arrangement of the plot yields is best expressed by a table of the coefficients of variability (V), where V is the standard deviation (σ) expressed as a percentage of the general mean of all plots.

The number of replications necessary to prove a difference of 10% between any two means may be calculated from V.* This has been calculated on the crop weights for the various combinations of shape and size of plot, and is presented in Table I, together with the coefficients of variability for each of the four cropping years and the total crop for the whole period.

The most reliable figures for comparison are those for the 1930 and 1931 crops, and for the whole period. The 1929 crop, being that of one-year-old plants, was light and variable, while by 1932, disease had taken such a hold that cropping was quite unreliable. It will be seen that with these large plots, doubling the size reduced the coefficient of variability in these years only by 1 or 2%, the approximately square plots being more accurate than those that were long and narrow. With the larger plots, the Latin square, giving a more efficient control of positional variation, gave somewhat more accurate results than six randomized blocks.

* Taking n as the number of replications, the standard error of the mean of n plots is $\frac{V}{\sqrt{n}}$, and the standard error of the difference between any two means, $\bar{x}_1$ and $\bar{x}_2$, of n plots is $\sqrt{\frac{2V^2}{n}}$. For significance Fisher's t test is used, where $t = \frac{\bar{x}_1 - \bar{x}_2}{\text{S.E. Diff.}}$, and for a 20:1 chance t is equal approximately to 2. Therefore for a difference of 10% between $\bar{x}_1$ and $\bar{x}_2$, $\frac{10}{\sqrt{\frac{2V^2}{n}}}$ = approximately 2, and n, the number of replications, is equal approximately to $\frac{8V^2}{100}$.

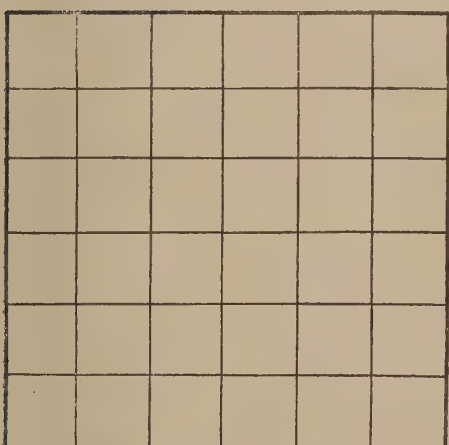




6 Randomized blocks.

(a) Plots $4 \times 23 = 92$ plants.

(b) Plots $8 \times 23 = 184$ plants.



6×6 Latin square.

Plots $8 \times 23 = 184$ plants.

6 Randomized blocks.

(c) Plots $4 \times 46 = 184$ plants.

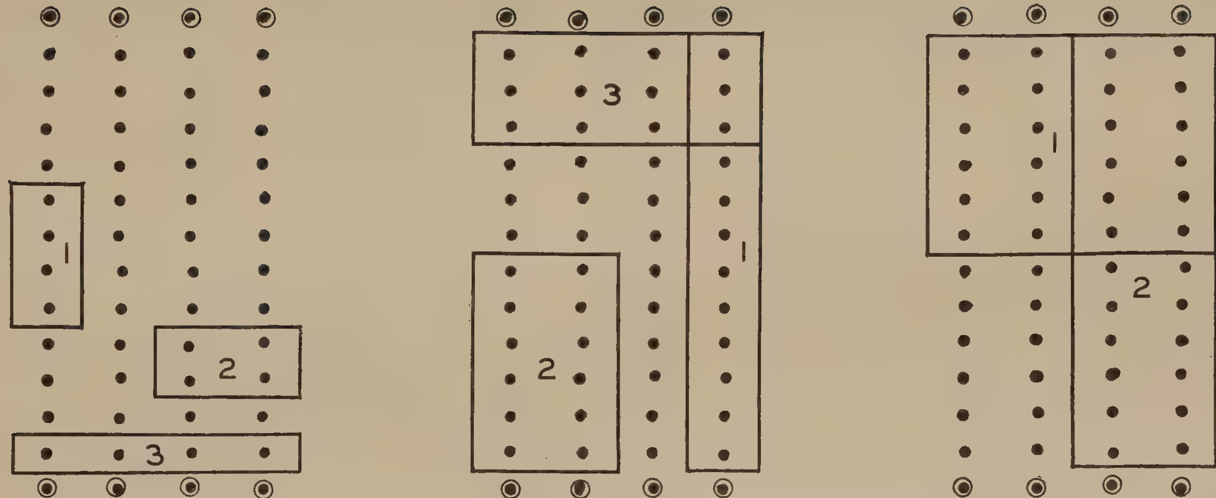
DIAGRAM I. Different arrangements and sizes of Plots in First Uniformity Trial (1928).

TABLE I.

Strawberry Uniformity Trial 1928.

Coefficients of variability and number of replicated plots necessary to show a difference in cropping of 10%.

Size and Shape of Plot.	1929.		1930.		1931.		1932.		Total 1929-32.	
	V.	No. Replicates.	V.	No. Replicates.	V.	No. Replicates.	V.	No. Replicates.	V.	No. Replicates.
I. 4 **Rows of 23 plants** ..	18·7	28	11·5	11	16·1	21	28·1	62	12·7	14
as 6 Randomized blocks	17·3	24	10·9	10	11·1	11	24·9	50	9·9	9
II. 8 **Rows of 23 plants** ..	16·3	22	8·7	7	14·7	17	21·7	36	10·9	10
as 6 Randomized blocks	15·0	18	8·1	6	8·9	7	17·3	24	7·4	5
as 6 × 6 Latin square	9·7	8	7·4	5	7·4	5	16·2	21	6·0	4
III. 4 **Rows of 46 plants** ..	16·9	23	9·6	8	15·0	18	24·2	46	11·8	12
as 6 Randomized blocks	15·8	20	9·1	7	9·4	8	20·9	35	8·7	7



4-PLANT PLOTS.

1. 1 × 4
2. 2 × 2
3. 4 × 1

12-PLANT PLOTS.

1. 1 × 12
2. 2 × 6
3. 4 × 3

24-PLANT PLOTS.

1. 4 × 6
2. 2 × 12

● = Experimental plant. ⊙ = Guard plant.

DIAGRAM 2. Different sizes and shapes of Plots in Second Uniformity Trial (1933).

At the best, with 92 plants to a plot (about 1/100th acre), ten or eleven replications would have been required to show a 10% difference in individual years of full crop, or nine replications for the whole period. By doubling the size of plot, the number of replicates could have been reduced to six or seven, for individual year differences to be established, or five for the total of four seasons. If the most efficient arrangement, such as a Latin square, had been used, five replications would have been sufficient.

The spread of disease in 1932 so increased the variation that, in the fourth year of cropping, it would have needed at least twenty replications of nearly 200-plant (1/50th acre) plots to show a 10% difference.

It was evident therefore that until something could be done to produce more uniform material no great advance could be made in studies involving fine shades of difference in strawberry cultivation, without occupying a fairly large area of ground. It was at this time that the attempt to produce more uniform material, by building up a new clonal race (as described elsewhere (4)), was begun.

The Second Trial.

In the spring of 1933 sufficient material of one single clone was available to plant another uniformity trial. This was planned in such a way that further information on the effect of time of origin on the mother plant might be obtained, and the results are discussed elsewhere (4).

The trial was designed as a 5×5 Latin square, each of five groups of runners, produced at different periods of the same season, being repeated in five plots. Each of the 25 plots consisted of 48 experimental plants in four rows of 12, with an extra guard plant at each end. For the first time, detailed records of height, spread and crop weight of *each individual plant* were obtained over a three-year period. It was thus easy to subdivide the original plots into smaller ones of varying shapes and sizes. The plants were de-blossomed in the first season (1933), but the crop in 1935 unfortunately cannot be taken as representative, as it was spoilt by the severe frost in May of that year. There is thus only one full cropping season for consideration.

As has been shown (4), the differences between the plots, due to age of plant, evened up in the first six months ; but in any case, any differences which remained were eliminated, together with those due to position, in the analysis of the data. The remaining variation, which is to be considered here, can be regarded as that of the material apart from that due to position or to time of origin of the runners.

The 25 plots, each of 48 plants, were split into 4-, 12- or 24-plant plots consisting of one, two or four rows as shown in Diagram II, and the various observations were totalled and analysed for each new plot arrangement. The results of these analyses are presented in Table II.

TABLE II.

Comparison of the relative accuracy of varying sizes and shapes of plots of Royal Sovereign strawberries—by means of the coefficient of variability (V).

Date.		Record.	Four Plant Plots.			Twelve Plant Plots.			Twenty-four Plant Plots.		Forty-eight Plant Plots.
			1×4	2×2	4×1	1×12	2×6	4×3	2×12	4×6	4×12
May	1933.	Spread.	16·1	16·5	16·4	11·5	9·6	8·8	7·9	5·7	6·9
Oct.	1933.	Spread.	12·4	12·0	11·9	7·8	7·7	6·6	5·6	5·7	4·9
		Height.	14·4	13·6	13·7	9·9	8·1	6·4	6·6	4·7	4·0
May	1934.	Spread.	12·7	12·5	12·2	8·4	7·3	6·4	6·2	3·7	4·0
		Height.	13·5	13·4	13·6	8·6	8·1	7·4	6·6	4·7	3·7
		Blossom Trusses.	19·2	19·0	18·8	12·3	12·4	10·4	10·2	7·6	6·6
July	1934.	Crop Weight.	18·3	17·7	18·5	11·3	10·6	10·1	8·6	8·5	5·4
May	1935.	Spread.	18·0	16·6	16·2	11·3	10·6	9·7	7·4	7·6	
		Height.	19·4	17·9	18·0	12·1	11·9	11·1	7·2	8·6	
July	1935.	Crop Weight.	31·8	29·1	29·9	22·5	20·0	16·7	16·0	14·1	
Sept.	1935.	Spread.	17·4	17·2	17·0	10·8	11·3	10·2	8·2	8·0	

It will be seen from the Table that V increases as the plants grow older. This is largely due to the fact that, where the plants died or had been removed, as a result of the Yellow-edge virus disease, some of the plots may not have retained their full quota of 4, 12 or 24 plants. This factor would naturally affect the smaller plots more than the larger. It is difficult to make allowances for missing plants in trials of this kind as, in addition to the missing plant itself, the neighbouring plants have not so much local competition, and have an advantage over the others. In large scale field trials, with this type of material, the most important record is that of the crop, and plot records of this are usually taken. If allowances have to be made for number of gaps, the making of records, as well as summarizing and analysing them, becomes complicated.

Firstly, it may be seen from Table II that, with plots of twelve plants or over, the 4-row plots were the least variable. The rows were three feet apart and the plants eighteen inches apart in the rows, so that any small soil differences would show themselves more in plots of plants in one row than in plots in which the plants were spread over four rows. In the 1928 trial the 8-row plots gave better results than the 4-row plots where the number of plants was the same. This greater variability of long narrow plots may also be the result of the spread of disease along rather than across the rows. Moreover, while single row plots are the easiest to plant and are quite satisfactory for some trials, plots having two, four, or any even number of rows, are easier to manage with unskilled labourers, who can conveniently work in pairs. Furthermore, in experiments which demand guard rows surrounding each plot, long narrow plots are less economical than square ones.

With all plots the coefficient of variability for size (height or spread of the plants) is less than that for blossom or fruit. This last is the most important record. For 4-plant plots in 1934, V was about 18% for crop, so that approximately twenty-seven replications were necessary to prove a 10% difference. In 1935, V greatly increased owing to a partial destruction of crop by frost and the rapid spread of disease in that year. This large number of replications is obviously impracticable, apart from the difficulty of making records of such small plots in a field trial.

For 12-plant plots the coefficient of variability for crop in 1934 was reduced to about 10·5%. These would need to be replicated about nine times to prove the same difference. This number is still rather large.

With the 24-plant plots there is a further reduction in V to about 8·5% and six replications would prove a 10% difference in the 1934 crop. Before the disasters of frost and disease in 1935, a similar difference in plant size could be proved with slightly fewer replicates.

The coefficients of variability for the 48-plant plots are calculated from analysis of the experiment treated as a 5×5 Latin square, taking out the positional

variance due to rows and columns and also that due to differences between the five time-of-origin-of-runner groups. These are not therefore strictly comparable with the 4-, 12- and 24-plant plots, since for the latter the whole of the variation between the large plots of forty-eight plants was eliminated.

In analysing the records made in 1935, one plot had to be discarded on account of a severe attack of the Yellow-edge virus disease, which necessitated the removal of a large number of plants. Values of V have been calculated from the remaining twenty-four plots for the 4-, 12- and 24-plant plots, but the omission of one plot upset the analysis on the 5×5 Latin square for the 48-plant plots. The 1935 records are therefore omitted from the analysis of the 48-plant plots in Table II.

With the 48-plant plots the coefficient of variability is reduced to the region of 5·5% for crop, and rather less for plant size, after the first record of spread in May 1933 when it was 6·9%. This figure is rather higher, as it also is, with one exception, in the smaller plots, probably owing to variations in runner size within the five time periods, which very soon evened up. Four replications of this sized plot should thus be ample to prove the same percentage difference as before.

It may be noted here that a similar experimental design in the earlier trial gave a coefficient of variability of 7·4% in the first cropping season with 184 plants to a plot. With only 48 plants to a plot greater accuracy ($V = 5{\cdot}4$) has here been obtained, thus emphasizing the value of clonal selection.

CONCLUSION.

Although the second of the two trials met an untimely end, the accumulated experience obtained during the past decade has given definite information upon which to base the design of future experiments. It is evident that the more nearly square the plots the more accurate the results will be. They should always consist of an even number of rows to facilitate picking and recording.

Size of plot will always depend on the type of experiment and the necessity of keeping the balance between land and labour. Thus, if land is scarce and skilled labour available, small plots are better, but if the reverse is the case, few and large plots are more economical.

Although plots of approximately twenty-five plants (1/400th acre) are likely to give good results if repeated five times, the economy in ground so effected is hardly justified, when the danger of errors in picking becoming unduly important is considered. Further, diseased or damaged plants may greatly reduce their accuracy. Plots of about fifty plants (1/200th acre), repeated four times, will probably give as precise results as can be expected in ordinary single factor experiments ; but this replication may not be necessary in a complex trial involving a number of factors.

For cultural and manurial trials, even larger plots still are to be preferred, since they are more economical in guard rows. With them, however, multiple factor trials are more likely, and if a split-plot design is used, a minimum sized sub-plot of twenty-five plants may be quite practicable if guard rows are not required.

The importance of efficient disease control for accurate experiments may once more be emphasized.

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SUMMARY.

The experience gained over a period of ten years, during which two uniformity trials were carried out, has been used to estimate the variability to be expected in strawberry plants at present. The knowledge gained has been used to determine a suitable plot technique.

The great superiority of clonal material over normal commercial strawberries of a few years ago is amply shown, and the importance of efficient disease control is further emphasized.

With clonal plants, plots of about 1/200th acre (fifty plants—at 3 ft. × 1 ft. 6 in.), repeated four times, are shown to be sufficient to prove a 10% difference, but even smaller plots, with slightly higher replication, are shown to be quite practicable, if economy in ground is desired, if guard rows need not be considered, and provided disease is kept under control.

Square plots are always more efficient than long narrow ones.

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